PERSPECTIVES ON EYE-TRACKING

ELECTRO-OCULOGRAPHIC STUDIES OF PSYCHOTIC PATIENTS AND ALCOHOL ABUSERS

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Abstract

An electro-oculographic technique for the computerized study of the horizontal eye tracking performance of normal and various psychologically abnormal groups, in particular alcohol abusers and certain types of psychotic patients, was employed, the target stimuli involving periodic waveforms of constant velocity and duration. A number of quantitative measures of eye tracking performance of possible relevance in comparing these groups were developed and were used to explore various aspects of the disorders involved and to investigate the role of attention in eye tracking performance. The results of a series of studies, reported in five separate papers, were interpreted as suggesting that the distinction between schizophrenics and cycloid psychotics is a meaningful one, that eye tracking measures can be useful in distinguishing between the two groups, and that the mechanisms involved in eye tracking deficiences of psychotics and alcohol abusers differ. Macro squarewave jerks were found to be prominent in alcohol abusers not acutely intoxicated. Microtremor level phenomena, studied by means of spectrography, appeared to possess considerable potential for distinguishing between normals, psychotics and alcohol abusers, alcohol abusers not acutely intoxicated tending to show a lower and hebephrenic schizophrenics a higher microtremor rate than normals. Under more attention demanding conditions, macrolevel performance as measured in terms of noise/signal ratio was found to improve for all major subject groups, and microtremor level activity to increase. The results of employing an extended program for identifying the occurrence of various types of deviations in eye tracking performance suggested a multidimensional analysis including the parallel use of both global and more specific measures, to offer considerable potential for studying somatic and attentional correlates of eye tracking. The possible neural mechanisms basic to the results obtained are discussed.

Key words
eye movements, electro-oculography, smooth pursuit tracking, saccadic eye tracking, miniature eye movements, psychosis, schizophrenia, cycloid psychosis, alcohol abuse, attention

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PERSPECTIVES ON EYE-TRACKING

Electro-oculographic studies

of psychotic patients and alcohol abusers

av

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Electro-oculographic studies

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In the following presentation, these papers will be referred to by their Roman numerals.

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INTRODUCTION

The study of eye movements is a multidisciplinary undertaking that has attracted the interest of students in such varied disciplines as education, engineering, neuroanatomy, neurology, neuro-otology, neurophysiology, neurosurgery, ophthalmology, optometry, pharmacology, psychiatry and psychology. It has been suggested recently (see, for example, Lennerstrand, Zee, & Keller, 1982, p. 521) that one class of eye movements, that of smooth pursuit, is the most sensitive simple indicator of brain function the clinician has. Despite such apparent simplicity, many questions remain, of considerable interest both for psychological theory and psychiatric practice.

One question concerns the specificity of pursuit disruptions for various psychiatric conditions. Several studies (e.g., Holzman, Proctor, & Hughes, 1973; Holzman, Proctor, Levy, Yasillo, Meltzer, & Hurt, 1974) appear to suggest, in line with early findings of Diefendorf and Dodge (1908), the specificity of the pursuit dysfunction for schizophrenics; Holzman et al. (1973, 1974; see also Holzman, 1985, and Matthysse, Holzman, & Lange, 1986), in fact, speak of eye tracking dysfunction being a trait marker for schizophrenia. Such specificity has been challenged, however. Early criticisms of it were voiced by Couch and Fox (1934; for recent reviews of the literature, see Lipton, Levy, Holzman, & Levin, 1983; Holzman, 1985). The issue of specificity gives rise to questions concerning the psychologically relevant mechanisms involved in the pursuit disruptions evident in different clinical groups, and also concerning the stability of such dysfunctions, the diagnostic criteria to be employed, and what additional clinical groups should be considered. The question of psychologically relevant mechanisms is complicated by the fact that pursuit eye movement dysfunction occurs not only in psychotics, but also in persons with central nervous system disease, and in certain drug-induced states. Disturbances in pursuit have also been reported in subjects with reading deficiences (e.g., Bogacz, Mendilaharsu, & de Mendilaharsu, 1974; Shapira, Jones, & Sherman, 1980). Furthermore, smooth pursuit eye movements appear to constitute an age-dependent motor system which degenerates with age

(Sharpe & Sylvester, 1978). The present study aims, not at clarifying the precise nature of the brain functions which eye movements generally entail, a matter regarding which knowledge is very limited, but at exploring possibilities of achieving a more adequate empirical and theoretical basis for an understanding of pursuit dysfunctions as they specifically relate to various individual conditions of psychological interest.

As regards questions of the stability of the dysfunctions in different groups of patients, relatively little empirical work has been done (cf. Lipton et al., 1983). Concerning the question of diagnostic criteria, one should note the dependence of these upon how the diagnostic categories employed are defined. The viability of new and possibly better approaches to classifying psychiatric patients, particularly different types of psychotics, needs to be explored. Certain groups of patients are especially in need of study. Alcohol abusers, examined in three of the present papers, represent one such group that has received little attention thus far.

Another crucial issue pertains to the recording techniques available. The techniques commonly used at present--whether mechanical, optical or electrical--possess considerable limitations. There is hope, nevertheless, that many technical deficiencies can soon be overcome. In the area of electrooculography, which has been regarded recently (e.g., Quéré, Péchereau, & Lavenant, 1981) as the only method answering the immediate requirements of the clinician, use of direct current (d.c.) amplification to measure eye position during tracking, although seemingly ideal in theoretical terms and the method most commonly employed, has the disadvantage of electrode drift; this causes an unstable baseline, making analog-to-digital conversion of sustained pendular eye tracking unreliable. In the present set of studies, use was made instead of alternating current (a.c.) amplification, with the aim of avoiding such electrode drift.

Still another important issue concerns the measures to be employed. Ratings or quantitative description of tracking deviations commonly use global measures that seem to have been developed largely in consideration of their

convenience. One can argue that, for matters so much in need of basic research, global and more specific measures should be employed concomitantly, with a multidimensional analysis of the processes involved. Use of such an approach, with emphasis on physiological characteristics of seemingly strong psychological relevance, appears called for.

There is a wealth of psychological theorizing concerning attention. In psychiatry too, reference is often made to attentional processes, especially in connection with schizophrenia. As pointed out by Holzman, Levy, and Proctor (1978), empirical work in the area often fails to specify precisely the nature of the impairment involved, a common interpretation of the term "defect of attention" being the commonsense one of "not paying attention". Interest in eye tracking from attentional points of view gained considerable impetus through the development by Shagass, Roemer, and Amadeo (1976) of a procedure for placing arabic numerals on a pendulum target, the numbers displayed changing in the course of oscillation, and the subject being asked to read the numbers silently while tracking. Shagass et al. reported that tracking became smoother during such a number-reading task, although the differences between normals and patients remained. These researchers, as well as those in the Holzman-group who also incorporated the number-reading task into their procedures, employed single measures which were of a global kind only. Holzman, Levy, and Proctor (1978), who based their conclusions on use of a single such measure, found a nonvoluntary attentional disorder which they claimed could account for the eye-tracking dysfunctions that were noted. The present author argues that what is really needed, in order to account for possible differences between various more or less heterogenous groups of subjects, is a more multidimensional perspective, one which takes account of both higher and lower order processes, and of interactions within the highly complex neural apparatus.

Smooth pursuit and saccadic movements

The traditional view of the human eye tracking system is that it involves two types of eye movements: smooth pursuit and saccades, which differ in a functional (Dodge, 1903), anatomical (Bender & Shanzer, 1964; Pasik & Pasik, 1964) and physiological sense (Spector & Troost, 1981). Smooth pursuit eye tracking refers to the continuous foveation of objects that are moving in space. The speed of such tracking is usually limited to the range of 1 to 30 deg/sec (Young & Sheena, 1975; see also Leigh & Zee, 1983). Saccades, on the other hand, being high velocity eye movements with the function of changing foveal fixation and with peak velocities as high as 900 deg/sec (Boghen, Troost, Daroff, Dell'Osso, & Birkett, 1974; see also Leigh & Zee, 1983), only succeed to a limited extent in capturing the image of a moving target on the retina, but can nevertheless serve as a basis for a saccadic type of tracking (Rodin, 1964; Hartje, Steinhäuser, & Kerschensteiner, 1978).

Smooth pursuit and saccadic eye movements are mediated by the cortex of the anterior occipital lobes and by the frontal cortex, respectively. According to Gay, Newman, Keltner, and Stroud (1974), the horizontal pathways for both smooth pursuit and saccades descend to the paramedian pontine reticular formation (PPRF) and from there to the ceberellum, the former via the internal sagittal stratum and the pulvinar, the latter via frontomesencephalic paths. As pointed out by Leigh and Zee (1983), however, the descending pathways to the brainstem are not fully known, there probably being more than one descending pathway for each of the pursuit and saccadic "commands".

Image motion on the retina is considered to constitute the usual stimulus for smooth pursuit. Pursuit eye movements, however, have also been found to occur in the absence of visible stimuli, for example through perception of image motion itself (Mack, Fendrich, & Wong, 1982). Views differ as to what constitutes the principal stimulus for pursuit movements: target velocity (Rashbass, 1961; Robinson, 1965) or target position (Kommerell & Täumer, 1972; Pola & Wyatt, 1980). Under normal circumstances, information regard-

ing target motion seems to be a more important stimulus for generating movements than is information concerning target position (Leigh & Zee, 1983).

Ocular motor neurons, through phasic eye velocity commands from the burst neurons (the pulse of innervation) and through position commands from the tonic neurons (the step of innervation), carry information concerning both velocity and eye position. Pause cells are proposed to normally inhibit the burst cells from generating saccades. The pause cells themselves must be inhibited prior to and also throughout the saccade, in order to prevent the interruption of the saccade which is in progress. If the pause cells are constantly inhibited, the system, being unstable, will begin oscillating and will execute a sequence of saccades without any interval between them, a process which is similar in principle to what has been found in voluntary nystagmus (Shults, Stark, Hoyt, & Ochs, 1977) and also in ocular motor pathology (Zee & Robinson, 1979).

Theoretical considerations and experimental evidence suggest that, through processes of mathematical integration in a neural network (Skavenski & Robinson, 1973; Robinson, 1975), velocity commands are converted into position commands. Anatomically, the integrator may be hypothesized to be spread out over a number of brain structures, including the nucleus prepositus hypoglossi and the medial vestibular nucleus (Robinson, 1986), lesions of which may give rise to defects of neural integration and thus to deviant pursuit. Recent experimental evidence, however, provides no support to such integration taking place in the PPRF, although that structure has traditionally been referred to as containing the neural integrator (cf. Robinson, 1986). Information concerning differences between neural signals representing target velocity and eye velocity, i.e. a retinal error velocity signal, is central to simple models which consider smooth pursuit to function as a negative feedback control system (e.g., Young & Stark, 1963). Yasui and Young's pursuit model (1975) involves an internal representation of target velocity as the stimulus in eye tracking. Among more complex models which account for at

least some of the non-linearities in smooth pursuit such as referred to by St.Cyr and Fender (1968a,b), Robinson's (1982) model, involving cancellation of the vestibulo-ocular reflex, is particularly worthy of interest.

Neural activity influencing visual following movements may emanate, not only from areas of the brain stem and the cerebellum, but also from the accessory optic system. Activity of the latter sort seems to be of importance for optokinetic following movements in lower mammals that lack a fovea, although, as discussed in Leigh and Zee (1983), the role of this system in primates has not been adequately clarified. The cerebral hemispheres, on the other hand, do seem to be of very considerable importance for eye tracking in man, as evidenced by the impairment of pursuit performance toward the side of the lesion in cases of cerebral hemidecortication (Sharpe, Lo, & Rabinovitch, 1979). Furthermore, projections from the parietal cortex and adjacent areas to the brain stem and cerebellum can apparently influence smooth pursuit by directing visual attention to moving targets (Leigh & Zee, 1983).

Miniature movements

Miniature eye movements (cf. Ditchburn, 1973), comprising components traditionally referred to as microsaccades, drift and tremor, constitute a third class of eye movements, of very small amplitude (less than 1 degree). Such movements have been studied extensively during conditions of "steady" fixation (e.g., Barlow, 1952). Winterson and Collewijn (1976) conclude that microsaccades are very common, occurring at a rate of 1 to 2 per sec during normal fixation. In the literature, no systematic studies of miniature movements during visual pursuit appear to have been reported. Studying pursuit of low velocity (measured in minutes of arc per second), Yarbus (1967), however, noted the presence of small involuntary saccades with characteristics that differ only slightly from those found during fixation of a stationary object. As apparent in a figure which that author presents, high-frequency type tremor can also be present during visual pursuit.

Views as to the function of miniature eye movements differ. One view considers them to serve no purpose (Kowler & Steiman, 1979, 1980). Another considers such movements to keep the visual axis within a certain small target area while preventing the loss in vision which stabilization of the retinal image during very precise fixation would yield (Ditchburn, 1980). Obviously, the visual system pays a significant perceptual penalty for the presence of microsaccades, since any given microsaccade entails 50 to 100 msec of saccadic suppression (Zuber & Stark, 1966). According to Bridgeman and Palca (1980), the production of microsaccades may be regarded as tripling visual thresholds for over an hour each day.

Recording procedures

Different methods for the study of eye movements are reviewed by Ditchburn (1973), Young and Sheena (1975), Carpenter (1977) and Leigh and Zee (1983). As Carpenter (op.cit.) remarks, no system has yet been devised to meet all conditions wished for by the researcher; methods of reflection, electromagnetic recording, electro-oculography and direct viewing, as well as devices using reflected light, all have their advantages and disadvantages. Electro-oculography and infrared reflectometry have been the two methods most commonly employed, these being found to produce quite similar results. Holzman (1985) sees this as making it unlikely that eye tracking dysfunctions obtained in psychotics represent simply artifacts of recording methods. The electro-oculographic method, being non-invasive and of minimal discomfort, stands out as the presently most practical method for recording eye movements. With that method, a permanent potential difference between the cornea and the retina (retina negative) of up to 1mV sets up an electric field which moves as the eye rotates. Skin electrodes placed at the outer canthus of each eye measure conjugate eye movements in the horizontal plane (Shackel, 1967; see also Young & Sheena, 1975). A major disadvantage with the direct-current (d.c.) electro-oculographic method commonly employed, however, is electrode drift, which results in an unstable baseline.

Visual tracking of a moving target usually involves movements of the eyes and the head together. On the other hand, laboratory studies of visual tracking traditionally make use of the restraint of holding the subject´s head stationary, such intervention attempting to control the vestibular and proprioceptive input to the pursuit eye movement system which takes place when free head movements occur (Meiry, 1971).

Quantification of pursuit

A variety of methods for the assessment of eye tracking performance have been reported in the literature. Tose of a more subjective nature include the use of rating schemes (Benitez, 1970; Shagass, Amadeo & Overton, 1974; Shagass et al., 1976; Iacono & Koenig, 1983) and of various other means of categorization on the basis of subjective visual inspection (e.g., Noorden & Preziosi, 1966; Maspetiol, Semette, & Jackowska-Hedemann, 1967, Corvera, Torres-Courtney, & Lopez-Rios, 1973, Bogacz et al., 1974, Bogacz, Mendilaharsu, & de Mendilaharsu, 1977). Obviously, basing the classification of pursuit movements on subjective judgments and using global eye tracking measures to diagnose neurological abnormalities is less than satisfactory even though the reliability of such judgments may be reasonably high.

Accordingly, attempts have been made to quantify pursuit function in various other ways. Holzman et al. (1973) developed a method for scoring non-obligatory velocity arrests, recording the number of times the eye stops when it should be moving in pursuit of the target (cf. Shagass et al, 1976). The result obtained has been criticized as representing an artifact of recording technique (Troost, Daroff, & Dell´Osso, 1974; Lindsey, Holzman, Haberman, & Yasillo, 1978; Iacono & Lykken 1981). Thus, for example, Lindsey et al. (op.cit.) argue that the velocity arrest score is contaminated by biopotential noise. A related method involves the counting of saccades as they intrude on smooth pursuit (Cegalis & Sweeny, 1979; Mialet & Pichot, 1981). Like the velocity arrests indices, this measure samples only one aspect of tracking error, the relevance of which is by no means clear. Other measures include

amplitude, phase, and the determination of gain as defined, for example, as the ratio of maximum velocity of pursuit to target velocity (cf. Baloh, Kumley, Honrubia, Sills, & Konrad, 1980; Schalén, 1980), where the rationale of each of these may or may not be central to the phenomenon under study.

Computerized scoring allows a number of additional scoring techniques to be employed, for example those using Fourier analysis (e.g., Correia, 1974). Lindsey et al. (1978) have developed a frequency analysis score, expressed as the natural logarithm of the signal-to-noise ratio of integrated power (ln S/N). Iacono and Lykken (1979a,b) have introduced the root-mean-squared (RMS) error deviation to quantify tracking performance. Both these latter methods have been shown to be similar (Spohn & Patterson, 1979) and even interchangeable (Lykken, Iacono & Lykken, 1981). As pointed out by Lipton et al. (1983), RMS error and ln S/N seem to have been developed as scores of convenience rather than being based on a conception of pursuit dysfunctions; a specification of what precise pattern of eye movements is involved is lacking.

Smooth pursuit and psychoses

Already in 1908, Diefendorf and Dodge, using a photographic technique, reported that the ability to carry out pendular pursuit movements is impaired considerably in many persons with mental disease, to a particularly marked degree in cases of schizophrenia, termed dementia praecox at the time. As evidenced by the photographic registrations the authors presented, the pecularities they observed in these patients, in particular that of a hesitation to adopt the pursuit swing, bear close resemblance to saccadic eye tracking. Such deficits of pursuit were reportedly not restricted to dementia praecox, although they appeared to be found in other patients only when the clinical condition of these patients had deteriorated considerably. The phenomenon was interpreted as a manifestation of the inability, characteristically found in praecox patients, to adapt to new and unusal requirements of the environment, rather than as a manifestation of defective attention.

Repeating the Diefendorf and Dodge experiment on 117 mental patients (mainly schizophrenics, psychoneurotics, and manic-depressive psychotics), Couch and Fox (1934) found gross pursuit defects in 18 of their patients. Although those patients appeared to be the most seriously ill of all the patients in the group, only 5 of the 18 were schizophrenics, suggesting the disturbance to not be specific for schizophrenia.

Renewed interest in the phenomenon of deviant pursuit in psychotics was manifested in the work of Holzman et al. (1973, 1974). Like Diefendorf and Dodge, these authors found pursuit disorders to be significantly higher in schizophrenics than in other psychiatric patients. Furthermore, they found disorders of smooth pursuit to occur in many first-degree relatives of schizophrenic persons, suggesting that eye-tracking dysfunctions may qualify as a genetic marker of a predisposition to schizophrenia (cf. Holzman, Kringlen, Levy, Proctor, Haberman, & Yasillo, 1977). Lipton et al. (1983) indicated studies from a number of laboratories to show an impairment of smooth pursuit eye movement in both schizophrenic patients and their biological relatives. Those authors, and various of the authors they cite, challenge the specificity of the disorder for schizophrenia and indicate such impairments to also occur in a considerable (though lesser) number of patients with other functional psychoses, as well as in certain central nervous system disorders.

Smooth pursuit and drugs

The influence of drugs on smooth pursuit has been documented by several investigators (for a review, see Leigh and Zee, 1983, p. 244). Alcohol is believed to decrease smooth pursuit velocity, with frequent catch-up saccades being required to maintain foveation, this resulting in saccadic pursuit (e.g. Drischel, 1968; Wilkinson, Kime, & Purnell, 1974; Guedry, Gilson, Schroeder, & Collins, 1975; Baloh, Sharma, Moskowitz, & Griffith, 1979; Levy, Lipton, & Holzman, 1981). Similar disruptions have been observed in subjects under the influence of barbiturates (Rashbass & Russell, 1961, Norris, 1968, Holzman, Levy, Uhlenhuth, Proctor, & Freedman, 1975). There is considerable support

for the view, however, that impaired pursuit in schizophrenics is not a consequence of drug treatment, at least of treatment by antipsychotic, and tricyclic, bicyclic, and tetracyclic antidepressants (see Levy, Lipton, Yasillo, Peterson, Pandey, & Davis, 1984, for a summary of recent findings). As regards drugs used to treat states of depression or manic depressive syndromes, association between impaired tracking and treatment with monoamine oxidase inhibitors and with lithium carbonate appears to be well documented (Levy et. al., 1981, 1984). The measures employed for studying the effects of drugs have been of a global type. Thus, for example, Levy et al. (1984) employed a signal-to-noise score, which regarded the power in a frequency band centered at 0.4 Hz as "signal" and the power in a band between 1.2 and 12 Hz as "noise".

Eye tracking and attention

A general view in recent literature (e.g., Levin, 1983, Lipton et al, 1983) has been that smooth pursuit dysfunction reflects more than mere inattentiveness or lack of motivation. In studying the role of attention in smooth pursuit, Shagass et al. (1976) found that requiring a subject to read numbers on an oscillating target improved poor eye tracking considerably, both for psychotic patients and normals, although the differences between the two groups remained. As the authors noted, subjects appeared quite oblivious not only of any original deficits in tracking but also of the improvement in tracking with the presentation of numbers. Smooth pursuit dysfunction appeared to these authors to represent a disorder of involuntary attention.

Repeating basically the same experiment, Holzman, Levy, and Proctor (1976) obtained essentially the same results but argued instead that smooth pursuit dysfunction represents a disorder of non-voluntary attention. By way of analogy, these authors indicated that many organic deficits can be circumvented by introducing the use of other, intact factors; they considered as example the Parkinsonian patient whose intention tremor diminishes or stops during a purposeful act such as reaching for an object. The author emphа-

sized, however, that from this one cannot reason that the absence of compensating mechanisms, such as a purposeful act in the case of the Parkinsonian patient, is the basic cause of the dysfunction--or in the case of eye tracking that the basic cause of difficulties lies in the voluntary realm simply because the carrying out of a voluntary act alleviates or diminishes the dysfunction. Instead, Holzman et al. maintain that dysfunctions of smooth pursuit should be viewed as a failure of cognitive centering, a failure which occurs despite the intention of carrying out the task.

The same authors (Holzman et al., 1976) noted that the improvement in eye tracking performance with inclusion of the number reading task was much greater (a) under conditions where smooth tracking had been replaced by saccades, than (b) under conditions where rapid movements of small amplitude appear and the general form of smooth tracking remains intact but tracings of a cogwheel-type can be noted. Holzman and Levy (1977) suggest that in the former case, i.e. in (a), the smooth pursuit system fails to adequately be utilized and is sluggish in being introduced; here the "more commanding stimulus than the pendulum alone" (Ibid, p. 21), which introduction of the number task produces, overrides the sluggishness. In contrast, the authors consider the "intrusive activity" (p. 21) of small amplitude rapid movements (cf. (b)) to be less affected by the change in stimulus.

As Holzman and Levy (Op. cit.) indicate, Heywood and Churcher (1971) considered the inhibition of saccades to be necessary for effective eye tracking. Holzman et al. (1978) in turn suggest that the improvement in eye tracking performance which they found the introduction of a number task to produce, mobilizes another cognitive system, one requiring a different quality of attending than in simple eye tracking. The latter authors indicate one aspect of the findings in question they consider to be of special psychological interest. This is the fact that in such an experiment, in contrast with most situations, the superimposing of one task upon another facilitates rather than interferes with task performance. The authors suggest the basis for this to be that the task which required non-voluntary attention was synergistic to

the one which required voluntary attention. The authors reasoned that "neural noise" (cf. Gregory, 1959)--emanating from some modulating, inhibiting, or integrating system, possibly situated in the brain stem--might be one basis for impaired tracking in psychotics as compared with normals, though no direct measure of such a phenomenon was obtained.

The present author, though likewise making no attempt to register neural noise as such, goes a stage further in the direction of microprocesses than did the Holzman or Shagass groups. This is to be seen in the present author's examination of microtremor phenomena.

AIMS OF THE STUDIES

The aims of the investigations included in the thesis are

to develop an electro-oculographic technique for the computerized on-line study of eye tracking performance, using a controllable stimulus of constant speed;

to develop a number of quantitative measures of possible relevance for comparing the eye tracking performance of defined clinical groups, especially psychotics and alcohol abusers;

to utilize these measures to explore various aspects of the disorders involved;

to investigate the possible role of attention in eye tracking performance;

to explore the use of a multidimensional perspective for the analysis of eye tracking performance;

to attempt to achieve a psychologically more adequate account of the relation of eye tracking performance to behavior in general, particularly as regards characteristics of various psychologically abnormal groups.

MATERIAL AND METHODS

Production of the stimulus and the tracking task

In an effort to construct equipment producing a controllable stimulus of constant speed, in contrast to the bob-and-string arrangement traditionally employed, an electronic pendulum consisting of a series of red light diodes displaying movement of a sinusoidal character was produced initially (described in I). After this had been built, the technical developments available were utilized to construct another pendulum, employing light diodes of a special type able to light up either red or green (as also described in I). The latter type of pendulum, involving what can be represented as a saw-tooth type stimulus movement of constant speed, was the only one of the two employed in the studies that followed (II-V). However, possibilities of developing on-line techniques led to the construction of a third pendulum, functioning in transparent mode together with a terminal and a minicomputer (see V). In all the studies, subjects were seated 0.5 m from the pendulum, their head movements restrained by a chin support. Subjects received the general instructions to follow with their eyes the movements of the pendulum. In Paper I, reporting on investigations employing both the sinusoidal and the saw-tooth pendulum, half of the subjects were presented with the sinusoidal pendulum first and with the saw-tooth pendulum thereafter, and for half the subjects the order was reversed. In the studies reported in Papers II-V only a pendulum of the saw-toooth type was employed. The sinusoidal pendulum was tracked for 60 sec, the task with this pendulum involving a single tracking period. The total time of tracking the saw-tooth pendulum was 300 sec and comprised three different tracking periods. In the first period, comprising 30 sec, the target was red. In the second period, which involved 180 sec of tracking following a 60 sec pause during which additional instructions were given, the stimulus color changed temporarily to green at short irregular intervals. The third tracking period, 60 sec in length following a 30-sec pause, involved (just as did the first) a red stimulus only. Subjects were to press a button each time the light changed to green, a green segment, when occurring, comprising a quarter of

a "swing" of the pendulum in the one direction or the other.

Recording techniques and methods of collecting data

All experiments involved the use of silver-silverchloride electrodes, which were placed on the outer canthi of the eyes, with a ground electrode over the middle of the forehead. Placement of the electrodes close to the temples aimed at minimizing the appearance of blinks in the recordings. In the studies reported in two of the papers (III, IV), additional electrodes were placed above and below the right eye to control for the appearance of blinks in the recordings.

Theoretically speaking, d.c. amplification would produce an output signal corresponding to the relative position of the eyes. The drawback of that technique, however, as was obvious from these initial attempts, was the occurrence of baseline drift, resulting in records of only limited value for the more extensive computer analysis aimed at.

Alternating current (a.c.) recording, on the other hand, has the advantage of high sensitivity recordings without, theoretically speaking at least, record drift off scale (Young and Sheena, 1975). In a.c. amplification, the signal returns exponentially to the base value, even when the input signal is constant, the time for reaching a third of the initial value of the output being defined as the time constant.

Consequently, in all five studies a.c. recording was employed as the method of choice. The first paper (I) used a Siemens-Elema M81 mingograph with a high pass filter (time constant 2.5 sec, corresponding to 0.07 Hz) and a low pass filter (cut-off frequency 30 Hz) for noise reduction. The succeeding papers (II-IV) used a Beckman R-511A Dynograph Recorder for which the longest time constant available using the voltage coupler of the equipment was 1 sec (0.16 Hz).

In papers I-IV rectilinear records of the input signals were displayed on ruled

Z-fold chart paper, using the ink writing technique of the respective mingographs for quick visual inspection and calibration purposes, records of the horizontal movements being stored on a Tandberg (TIR) FM tape recorder for subsequent analog-to-digital conversion. Data for any given subject were obtained from separate analyses of different 30-sec segments of the total tracking task. In Paper I, this involved the computation of five periods of tracking, where Period 1 represents the initial 30 sec-segment of the sinusoidal pendulum task, whereas Periods 2-5 involved successive portions of the saw-tooth pendulum task--Period 2 representing the initial 30 seconds of the first of the two red-light-only tasks, Period 3 the initial 30 seconds of the red-and-green-light tracking task, Period 4 a 30-sec segment of the latter task commencing 90 seconds after the end of Period 3, and Period 5 the intial 30 seconds of the second red-light-only tracking task. Calibration was facilitated by having the subject shift his gaze several times between the two endpoints of the pendulum. Such calibration was carried out before each of the 60 or 300 sec tracking periods. The tape recorded signals from any given period were digitized at a rate of 8,200 sampling points for the 30 seconds involved. In Papers II-V, where only the saw-tooth pendulum was employed, the ABBA-type design from Paper I designed for the collection of data using this type of pendulum involved the analysis of four 30-sec periods only, where Periods 1 and 4 comprised the initial tracking segments of the red-light-only tasks, and Periods 2 and 3 both segments of the red-and-green task. In Paper V, use of mingographic presentation of the input signals was abandoned, the corresponding analogue 30-sec signals being digitized directly. Calibration in this latter study involved use of the terminal screen instead of the mingograph in controlling for deflection of the eyes.

Treatment of data

The a.c. output does not necessarily provide an accurate representation of eye position. This problem was handled in Paper I through attempts to reconstruct eye position (P) from the recorded output (V) through solving the

differential equation $dV/dt = a \cdot dP/dt - b \cdot V$, where dV/dt represents change in V over time. As was obvious from the recordings in Paper I, drift in the measurement equipment could still occur, which necessitated use of a linear correction. In the subsequent studies, a time-constant somewhat shorter than the one used in Paper I but still rather long (1 sec) was employed; this reduced the need for use of a correction. In Paper V, trials with the on-line equipment were carried out without corrections, the relatively long time constant that was still used and the negligible occurrence of electrode drift making such correction appear superfluous.

Processing of data in Papers I-IV involved the shortening of each digitized segment to exactly 12 cycles, a preliminary Fourier analysis being used to identify cycles.

In Paper IV, a separate study (named Study II in that article) was devoted to an attempt at identifying the occurrence of various types of tremor. To this end, two types of smoothing of the eye position curve were performed, based on the computing of sliding means over 16-point and 128-point intervals, respectively, one interval corresponding to 10 msec. The two types of sliding curves were referred to as the V4 and the V7 curve, respectively.

The experiments in Paper V, which aimed at identifying what frequency components are present during tracking under less attention demanding and more attention demanding conditions, employed spectrography and digital Fourier transforms, using Hanning window, of the entire output signal.

Measures obtained

In Papers I-IV, processing of the data from any given segment was carried out separately for each of the digitized periods. In each study, the following summary measures of the subject's overall tracking performance (OTP) were calculated:

1. Noise/signal ratio: the ratio between the squared amplitudes of the 2nd,

3rd, 4th, 5th, and 6th harmonics, and the squared amplitude of the major wave (1st harmonic). For a subject following the pendulum closely, this measure would be low.

2. Deviation area: the area between the two curves describing the movements of the pendulum and of the subject´s eyes, respectively. If a subject followed the pendulum closely, this measure would be low.

3. Microtremor rate: (d(tot)-d(eff))/d(eff), where d(tot) represents the total distance and d(eff) the effective distance the eye covered, and where d(tot) and d(eff) represent the sum of all small eye movements, as measured by recording eye position at 3.66 msec intervals, and at intervals nine times larger (33 msec). In Paper V microtremor rate was computed as well.

In addition, the following overall measures were employed in Paper I:

4. 2nd, 3rd, 4th, 5th and 6th harmonics: the ratio of the respective higher harmonic factor (i.e., 2nd, 3rd, 4th, 5th and 6th harmonic factor) to the 1st harmonic factor. These measures were also utilized in Paper II.

5. Number of crossings: the number of times the movements of the pendulum and the curve describing the movements of the subject´s eyes crossed each other.

6. Mean reaction time (MRT): the mean of the subject´s reaction times in pressing the button when the light in the pendulum became green. The reaction times were measured by inspection of the mingograph record, the mean reaction time being computed for the 180-sec tracking period during which the color of the light in the pendulum could change.

7. Standard deviation of mean reaction time (SDMRT:) the standard deviation of the subject´s reaction time.

8. Misses and false alarms: the number of times, in the 180-sec tracking period during which light in the pendulum could change, that the subject failed to press the button when it should have been pressed (miss) or pressed

the button when it should not have been pressed (false alarm).

In article V, one of the two studies involved computation of deviations from two types of sliding curves, the V4 and the V7 curves (see above), the former type being seen as a fine and the latter as a coarse representation of the subjective stimulus curve.

9. Macrotremor, i.e. deviations from the V4 curve: computed by identifying and counting the upward and downward deviations of the eye position curve from the V4 curve and then identifying bands of adjacent deviations. The analysis aimed at finding bands of deviations of roughly equal size, single rapid changes being excluded automatically, through a rule by which any deviation, the neighbors of which were less that half as large, was eliminated. For each tracking period, the following computations were obtained: a) number of macrotremor deviations; b) mean size of the macrotremor deviations, c) mean width of the macrotremor deviations, d) mean speed of the macrotremor deviations; e) percentage of the V4 which the macrotremor deviations encompassed.

10. V7-deviation measures: on the basis of deviations of the V4 curve from the V7 curve the following measures were computed for each of the four periods of testing: f) number of deviations of the V4 curve from the V7 curve; g) mean size of deviations under f); h) number of deviations greater than 2.1 degrees; i) mean size of deviations under h); j) number of jerks, i.e. deviations greater than 3.15 degrees; k) mean size of jerks; l) mean slope of jerks; m) mean number of recoils; n) percentage of the V7 curve involved in recoils; o) number of plateaus; p) mean number of macro squarewaves, i.e. deviations that began and ended with a jerk and where the line between the jerks was flat, horizontal and of minimum temporal size.

In the case of the saw-tooth pendulum, for each measure above, a summary measure of the subject´s overall tracking performance was calculated, as were also two difference scores, employing measures 1 - 8 in Papers I - II and the first study of Paper IV, and 9 - 10 in the second study of paper IV:

11. Dif-1: the difference between the sum of the raw-score measures obtained on the first and last periods that involved red lights only and the corresponding sum of the measures obtained on the two periods involving red and green lights.

12. Dif-2: the difference between the sum of the raw-score measures obtained during the first two periods and the corresponding sum of the measures obtained during the last two periods.

Cluster analyses: Cluster analysis was used to group individuals according to their similarity in terms of a set of variables. In Paper I such an analysis was based on a partly arbitrary selection of measures comprising mean of subject's scores on noise/signal ratio, number of crossings, deviation area, microtremor rate, standard deviation of mean reaction time, and scores on Dif-1 of deviation area and Dif-1 of the 2nd harmonic. Prior to the clustering, a normalizing of the measures over subjects was carried out, aimed at transforming the measures to a scale of 0 to 1.0. This provided the basis for assigning each subject points on a cycloid or a schizophrenic index. The sums of the cycloid and schizophrenic index points the subject received formed the indices upon which the cluster analysis was carried out. The output of the latter was presented in a dendrogram showing subjects' similarity with one another.

In Paper IV, six different hierarchical clusterings of observations, using Ward's (1963) method, were carried out. The respective clusterings involved (1) all V4 (macrotremor) OTP scores, (2) all V4 (macrotremor) OTP, Dif-1 and Dif-2 scores, (3) all V7-deviation OTP scores, (4) all V7-deviation OTP, Dif-1 and Dif-2 scores, (5) all V4 (macrotremor) and V7-deviation OTP scores, and (6) all V4 (macrotremor) and V7-deviation OTP, Dif-1 and Dif-2 scores, for each of 14 subjects studied.

Spectrographic analysis: In Paper V, digital Fourier transforms of the 30-sec input signals, using Hanning-window, was employed for analyzing the frequency components in 5 Hz intervals from 0-50 Hz.

Subjects

Psychotic patients:

Paper I: Included in this study were 13 schizophrenics, four of the hebephrenic type, three of the paranoid, two of the catatonic and one each of the simple, residual, schizo-affective and chronic-undifferentiated type, and 9 cycloid psychotics (cf. Leonhard, 1957/1979), four of whom were classified as hyperactive and five as more or less inhibited at the time of testing. Of the patients, 9 were men and 13 women. Mean age was 29.7 years for the schizophrenics (s.d.=10.2) and 27.5 years for the cycloid psychotics (s.d.=6.9).

Papers II and III: The patients referred to in these studies were nine schizophrenics (5 men, 4 women; mean age 30.9 with s.d. = 8.9), four of whom were of the hebephrenic, three of the paranoid, one of the undifferentiated and one of the non-regressive (Nyman, 1975) type, and eight cycloid psychotics (4 men, 4 women; mean age 26.6 with s.d. = 5.6). The group in this study also comprised two manic-depressive psychotics (both men, ages 27 and 50). All subjects except four (two cycloid psychotics, one hebephrenic schizophrenic and the undifferentiated schizophrenic) were tested on two different occasions a week apart.

Paper IV: The group in this study included four psychiatric out-care patients who were tested once, three of them being diagnosed as schizophrenics (one male of the simplex type age 32.0, one male of the undifferentiated type age 55.3, and one female of the hebephrenic type age 28.8), the fourth subject, a female age 42.6, being diagnosed as a psychotic of undifferentiated type.

Alcohol abusers:

Papers III and IV: Twenty alcohol abusers (all males, mean age 41.2 with s.d.=11.3) were tested for Paper III, nine of them once and thirteen of them twice during the initial four month period of data collection (Paper III). During an extended period of testing reported on in Study I of Paper IV, three of the subjects tested twice for Paper III, aged 32, 34 and 43, were

retested once, seven and eight times, respectively.

Paper V's group included three alcohol abusers, ages 39, 59 and 47, respectively.

Normals:

Paper I's subjects included four normals (mean age=29.0 years; s.d=5.1), recruited from the clinic staff of the psychiatric hospital.

Paper IV's group included seven normals (mean age=37.6 years; s.d.=6.9) recruited among personnel of the health care center at which the investigation was carried out.

Paper V's group included three normal males (ages 41, 21 and 37, respectively).

RESULTS AND INTERPRETATION

Single measures (Papers I - IV)

Psychotic patients:

Paper I:

Results:

OTP (Overall tracking performance). Compared with cycloid psychotics, schizophrenics were found to be lower on noise/signal ratio, deviation area and standard deviations of mean reaction times and to be higher on number of crossings and on microtremor rate. All these differences except those for microtremor rate were significant at the 5% level. At the same time, the microtremor rate of hebephrenic schizophrenics was found to be significantly higher than that of non-hebephrenics and cycloid psychotics.

Dif-1 and Dif-2. No significant differences between the schizophrenic and cycloid psychotic groups were obtained in terms of Dif-1 and Dif-2 scores. For both patient groups, Dif-1 scores indicated that, under the more as compared with the less attention demanding conditions, eye pursuit perform-

ance improved as regards noise/signal ratio, deviation area, the 2nd harmonic and the 4th harmonic, although it deteriorated as regards the 5th harmonic. Dif-2 scores for both groups revealed an improvement in terms of the 4th harmonic and 6th harmonic, though not in terms of any of the other measures.

Interpretation:

The results were interpreted as supporting the assumption that the distinction between schizophrenics and cycloid psychotics is a meaningful one and that measures of eye tracking performance can be useful in distinguishing between the two groups. In addition, the fact that the hebephrenic schizophrenics displayed a much higher microtremor rate than the other patients was seen as suggesting that measure to be useful in differentiating schizophrenic sub-groups.

Furthermore, the fact that patients' performance improved when the task was made more complex was seen as supporting the Holzman et al. (1974) suggestion that central disturbances lie at the basis of patients' deficits. At the same time, the deterioration in patients' performance in terms of the 5th harmonic under the more attention demanding conditions was seen as reflective of cognitive strain here inducing the subject to employ a more simplistic cognitive strategy, that of not following the moving stimulus all the way to the end-point.

On the other hand, it was suggested that results concerning the more variable reaction times of cycloid psychotics than of schizophrenics may have been artifactual. The basis for this suggestion was the fact that the task conditions were rather similar to those of the Continuous Performance Test (Kornetsky, 1972), which has been used to demonstrate the improvement that may occur in the vigilance performance of schizophrenics after phenothiazine drugs have been administered. Since patients of both groups had received phenothiazine or phenothiazine-like drugs, and little is known of the effect of such drugs on the vigilance of cycloid psychotics, it was felt that the differences found could have been based simply on the effect of the drug.

Papers II and III:

Results:

OTP. Schizophrenics were found to be lower on deviation area and to be less extreme on noise/signal ratio than the patients with cyclic disorders (cyclic psychotics and manic depressives, though only two patients of the latter type were tested), the noise/signal ratio of the cyclic group tending more toward the two extremes. The result for deviation area just mentioned agreed with what was reported in Paper I. That result, as well as the result for noise/signal ratio, were both obtained on the first testing only, not on the retesting carried out with 15 of the 19 patients.

Dif-1 and Dif-2. The results for Dif-1 and Dif-2 scores at least partly corroborated, and in no case contradicted, the results reported in Paper I. As in the earlier investigation, no significant differences between the patient groups were obtained in terms of either Dif-1 or Dif-2 scores. Similarly, in agreement with what had been found in Paper I, Dif-1 scores indicated performance under the more as compared with the less attention-demanding conditions to improve in terms of noise/signal ratio, the 4th harmonic and deviation area, and to deteriorate in terms of the 5th harmonic. This was found to be the case both at initial testing and on retesting for noise/signal ratio and for the 5th harmonic, but to only be the case at initial testing for the 4th harmonic and for deviation area, results for the latter two measures failing to achieve statistical significance. An improvement in performance under the more as compared with the less attention demanding conditions was also found for microtremor rate, especially at initial testing. In agreement with what had been reported in Paper I, Dif-2 scores showed an improvement over time for the 4th harmonic, a result obtained both at initial testing and retesting, though neither result achieved significance. Dif-2 scores for both testing occasions indicated microtremor rate to show a significant decrease over time.

Interpretation:

The results concerning the psychotic patients were seen as providing cross-

validational support for many of the findings in Paper I, regarding both overall measures of deviation area and the tendency for performance to be better generally under the more attention demanding conditions. Just as in Paper I, opposite results were obtained for the 5th harmonic.

The somewhat enigmatic results regarding noise/signal ratio were seen as reflective of phasic changes in the cycloid psychotics. The changes may have been largely those of improvement, since in terms of deviation area the cycloid psychotics shifted, between the initial testing and the later testing about a week later, from being distinctly worse in performance than schizophrenics to not differing from them.

The importance of microtremor rate was highlighted in this paper. A partial explanation for the greater sensitivity of this measure here than in the investigation reported in Paper I, may be the fact that the amplifier was not identical with that used in the earlier investigation and that the value of high pass filter differed slightly for the two studies. Apart from the fact that results on this measure seem to be very sensitive to minor changes in instrumentation, the finding, consistent over test and retest, of microtremor rate increasing as cognitive strain increased but of its nevertheless decreasing over time, was seen as indicating this measure to be a meaningful one for further investigation of various aspects of the tracking task. The high degree of reliability also noted in the scores reflecting effects of variations in attention demands from the first to the second testing occasion, for deviation area as well as noise/signal ratio, was seen to roughly accord with the findings of Holzman et al. (1973) and Shagass et al. (1974) of high test-retest reliability in the patients they examined.

Paper IV:

Results:

OTP. The first study in this paper indicated the psychotic out-patients (n=4) to be higher than normals (n=7) on both noise/signal ratio and deviation area, wheras no differences were found between the psychotic patients and the normals on microtremor rate.

Dif-1 and Dif-2. No clear differences between groups were found on these measures in the small group of psychotic out-patients studied here.

Interpretation:

The results were interpreted as indicating different mechanisms to be involved in the eye tracking deficiences of psychotics and alcohol abusers. It should be noted, however, that the psychotics tested in this study differed from those tested in the earlier studies in being out-patients at a primary health center and not in-patients at a psychiatric hospital.

A l c o h o l a b u s e r s:

Paper III:

Results:

OTP: No significant differences were found between the alcohol abusers and the psychotic patients on noise/signal ratio and deviation area, either on the first testing or at retesting. Normals generally were relatively low on both the measures. As to microtremor rate, a categorical difference was found, all of the alcohol abusers scoring lower than any of the psychotic patients. On this measure, the normals all showed values relatively similar to those of the alcohol abusers.

Inspecting the recordings for irregularities indicated the presence, in the majority of the alcohol abusers, of macro squarewave jerks in the same direction as that of the target, such deviations consisting of an initial saccadic deviation of at least 10 deg amplitude from actual tracking, followed after about 200 msec by a catch-up saccade in the direction opposite to that of the initial saccades. Such deviations rarely occurred among psychiatric patients in the studies reported in Papers I and II. The macro squarewave jerks were not associated with blinks and were found to a significantly higher extent in heavy abusers than in mild but did not seem to be present in a heavy alcohol abuser who when tested was still under the direct influence of ethanol.

Dif-1 and Dif-2: For Dif-1 scores on noise/signal ratio, a tendency was found, although not significant, for the tracking of alcohol abusers to be better under the more than under the less attention demanding conditions, quite in line with the significant result with this measure for the psychotic patients studied in Papers I and II. Dif-1 scores for deviation area showed no such indication as had been found in psychotic patients for performance to be better under the more than the less attention-demanding conditions. A tendency for microtremor rate to be higher under the more than under the less attention demanding conditions was found at initial testing but not upon retesting, a result which was quite similar to that obtained for the psychotic patients considered in the same paper. For Dif-2 scores on noise/signal ratio a significant improvement over time was found for the tracking of the alcohol abusers. This result was contrary to what was found for the psychotic patients with whom they were compared, a deterioration over time, though not significant, being found for the latter group. There was a non-significant tendency for the microtremor rate of the alcohol abusers to decrease over time, the tendency not being as clear as that found for the psychotic patients.

Interpretation:

The rather unexpected finding of macro squarewave jerks being prominent in heavy alcohol abusers, at least when not acutely intoxicated, was seen to suggest pathological involvement to lie at the basis for the macro squarewave jerk phenomenon (cf. Dell'Osso, Troost, & Daroff, 1975). Since no evidence was found for the initial, abnormal saccade of the phenomenon to be correlated with delayed foveal targeting, the phenomenon seemed to be open to interpretation in terms of a saccadic pulse generator being triggered by an unwanted supranuclear command signal (cf. Zee and Robinson, 1979). The presence of such saccades, however, can be viewed as basically differing from the type of saccadic pursuit characteristic for acute alcohol intoxication, where this latter type represents a compensation for the delay in foveation which acute intoxication brings about.

The very large difference in microtremor rate between alcohol abusers and psychotic patients was interpreted, through somewhat arbitrarily using the results obtained on the normals in Paper I as a reference group, as suggesting disturbances of a central nature in the psychotic patients. The comparison with the normals here was based on the assumption that the slight differences in instrumentation which were present would not invalidate the comparability of the microtremor rates found in the various studies. The results for normals reported in Paper IV, based on instrumentation identical to that of this study, indicated alcohol abusers to also deviate from normals, tending to score lower than the normal subjects. This can again be seen to suggest central nervous system disturbances, though of a different kind from those of psychotic patients.

Paper IV:

Results:

OTP: The first study in this paper indicated the noise/signal ratio for two of the alcohol abusers, who were tested three and ten times, respectively, to be at the lowest level on those testing occasions when the subjects were directly under the influence of ethanol. Deviation area was found to fluctuate considerably in each of the alcohol abusers, being consistently lower under conditions of benzodiazepine medication for the two alcohol abusers who occasionally received it. Microtremor rate likewise showed considerable fluctuations over testing occasions in the alcohol abusers, scores on this measure too being low when subjects were on benzodiazepine derivates. Microtremor rate increased, however, under conditions of acute alcohol intoxication, the two alcohol abusers who were tested when acutely intoxicated showing microtremor rate of levels well above those registered in the psychotic patients and the normals.

In the second study in this paper, OTP-scores for deviations from the V4 curve (macrotremor) indicated the number of deviations (measure 9a), their mean size (9b), their mean velocity (9d), and the percentage of the V4 curve deviations comprised (9e) to be lower in the two acute alcohol abusers than

in any of the other subjects tested, the mean width of deviation (9c) also being relatively low in these two subjects. No categorical differences of the various sorts just mentioned (9a,b,d,e) were found between the normals and the psychotic patients, although three of the four psychotics scored higher than any of the normals on measure 9a (mean number of deviations per period). The fourth psychotic subject, who was at about the level of the normals on this measure, reported earlier periodic alcohol abuse.

OTP-scores for the V7-deviation measures indicated the total number of deviations (measure 10f) to be lowest for the two acute alcohol abusers and the psychotic patients, the mean size of all deviations (10g) and the height of jerks (10k) being highest in these subjects, whereas the sober alcohol abuser scored highest of all the subjects on measure 10f and lowest of all the subjects on measure 10k. Although the numbers of jerks (10j) and of recoils 10m were about the same in all the subjects, the alcohol abusers and the psychotic patients were found to differ categorically from the normals on the mean slope of jerks (10l), slope being steeper in the former group. The two acute alcohol abusers and one of the psychotics were highest of all the subjects on percentage of the V7 curve involved in recoils (10n) and on the number of plateaus (10o).

Dif-1 and Dif-2: In study I of this article, Dif-1 scores for the two alcohol abusers who were tested nine and ten times, respectively, indicated noise/signal ratio to be better generally under the more than under the less attention-demanding conditions, thus according with the general tendency of this sort obtained in the earlier papers both for alcohol abusers and for psychotic patients. In the two alcohol abusers, scores on deviation area tended to deteriorate upon continued testing under the more attention demanding conditions, contrary to the general tendency obtained for the alcohol abusers who were tested once or twice, reported on in Paper III. Dif-2 scores on noise/signal ratio indicated performance to deteriorate over time in all three alcohol abusers tested, whereas in Paper III a significant improvement in tracking over time had been noted on this measure. For deviation area the

Dif-2 scores also indicated tracking to deteriorate over time generally in most of the normals, psychotics or alcohol abusers, whereas for microtremor rate, although no clear tendencies were found in the alcohol abusers and the psychotic patients, the Dif-2 scores of all the normals but one decreased over time. It was noted that for two of the psychotic patients the decrease in microtremor rate appeared to be a drastic one, whereas the only normal not scoring higher over time on this measure came to the laboratory in a highly stressed state, showing a dramatic increase in microtremor rate over time.

Study II of this paper found no clear differences between the subject groups on the V4 Dif-1 scores. In both the alcohol abusers and the normals, V4 Dif-2 scores for each of the measures included indicated a decrease in values over time, the decrease being most obvious in the two acute alcohol abusers, whereas in psychotic patients an increase over time was noted. V7 Dif-1 scores showed the number of deviations (10f) to increase generally under the more attention demanding conditions for all subject groups. In the alcohol abusers, an increase in the number of deviations greater than 2.1 degrees (10h) was evident under the more attention-demanding conditions, whereas for the three schizophrenic patients a decrease was evident. The alcohol abusers also increased their numbers of jerks (10j), recoils (10m) and plateaus (10o) under the more attention demanding conditions. For the normals and the psychotics no consistent tendency of this sort was found for (10j), whereas for (10m) and (10o) the normals showed a picture similar to that of the alcohol abusers, the psychotics showing the opposite picture. For the V7 Dif-2 scores, the number of deviations (10f) was found to decrease generally over time for the alcohol abusers and the normals, whereas it increased over time for the psychotics.

Interpretation:

In connection with the first study, it was speculated that for the two acutely intoxicated alcohol abusers the rise of microtremor rate to about the level of normals might serve certain functional ends. The question was seen as an

open one whether the low microtremor rate of alcohol abusers when not acutely intoxicated was produced through their long-term alcohol abuse (quite apart from any medication they might have received) or was based on inheritance.

The apparent discrepancy between alcohol abusers and psychotics on their noise/signal ratio and deviation area scores under conditions of increased cognitive strain was seen as attributable to differences in the type of performance decrements involved. The lowering of microtremor rate upon medication with benzodiazepine, obtained in two cases involving alcohol abusers, suggests that drug to have a damping effect of short-term duration upon miniature eye movements.

The fact that the normal subjects did not improve very much on noise/signal ratio under the more attention demanding conditions was seen as due to the fact that, with tracking already being rather optimal under the less attention demanding conditions, no fundamental change in the basic tracking strategy was called for under the more attention demanding conditions.

The fact that one of the normals, tested when highly stressed, showed a dramatic increase in microtremor rate over time and that the same person achieved the best macrolevel tracking performance of all the normals tested, suggested stress to have a specific effect on microtremor rate. The achievement here of high macrolevel performance appeared to be at the cost of increased activity on the microtremor level.

The finding in the second study of the total number of V7-deviations being relatively low in the two acute alcohol abusers and in the psychotics, as compared with the normal subjects and the sober alcohol abuser, was seen as partly reflecting the fact that the mean size of such deviations was also highest among these two former groups of subjects. The typically saccadic tracking evident in acute intoxication appears to manifest itself in the relatively higher number of plateaus in these subjects. The fact that number of jerks and recoils failed to differentiate between the normals, on the one

hand, and the psychotic subjects and the acute alcohol abusers, on the other, whereas height and steepness of jerks did, appears to indicate that the generation of saccadic impulses per se is not of crucial importance for the smoothness of tracking and that instead a phenomenon such as excessive velocity or insufficient inhibition of saccades already released may be central to the dysfunctions. Such post-synaptic inhibitory activity may influence acute alcoholic abusers at a level below that of V7, as is evidenced by results obtained for the acute alcohol abusers on most of the V4 (macrotremor) measures. As the V4 Dif-2 scores also indicate, inhibition even increased over time in alcohol abusers, suggesting the inhibitory mechanisms here to be strongly associated with system fatigue.

The relatively low number of squarewave jerks found in this study as compared with those reported in Paper III can be seen as reflecting their occurrence primarily in sober alcoholics, where only one subject of this sort was tested here.

Cluster analyses (Papers I and IV)

The dendrogram presented in Paper I revealed all four normals to fall adjacent to one another, all of them showing low cycloid and schizophrenic indices, with values of 0 or 1; the hyperactive cycloid psychotics to form a group of their own, scoring highest of all subjects on the the cycloid index (with values of 6 and 7); and the schizophrenics and inhibited cycloid psychotics to not be separable from one another in the dendrogram. It was noted, however, that the two subjects scoring highest on the schizophrenic indices were both clinically diagnosed as schizophrenics.

The cluster analysis reported in Paper IV, based on all the OTP, Dif-1 and Dif-2 scores, succeeded quite well on the three-cluster level in distinguishing between the two acute alcohol abusers, the four psychotics and the seven normals, the sober alcohol abuser appearing in the same cluster as the normals. As pointed out by Groner, McConkie and Menz (1985), in commenting upon this study, the data analysis employed here can be seen as highly suitable in a situation where a large body of data exists concerning

only a few subjects.

Spectrographic analysis (Paper V)

The spectrographic analysis in Paper V indicated activity in the lower frequency bands, up to about 15-25 Hz, to decrease in all six subjects under the more as compared with the less attention demanding conditions. At the same time activity in the higher frequency bands, those between approximately 25 Hz and 50 Hz, tended to increase under the more attention demanding conditions in all three normals and in two of the three alcohol abusers, this increase occurring simultaneously with an increase in microtremor rate. The third alcohol abuser was relatively high in microtremor rate under both the less and the more attention demanding conditions and tended under the latter conditions to show a decrease in the frequency bands up to 45 Hz.

Normalizing the values for the frequency components by assigning the frequency band of 0-5 Hz a value of 1000, indicated the relative energy within the higher frequency bands (25-50 Hz) to increase for all subjects under the more attention demanding conditions.

The findings in this study, involving spectrographic analysis of the entire 30-second signal, were seen as providing a picture of phenomena at the microtremor level highly similar to that obtained through measurement of microtremor rate. Obviously, the effects of different low-pass and high-pass filters on the results obtained is in need of further exploration.

GENERAL DISCUSSION

Numerous investigations have shown a large percentage of schizophrenic patients to display pursuit dysfunctions (e.g. Holzman, 1975, 1985; Holzman & Levy, 1977; Lipton et al., 1983). The study reported in Paper I, which took the early work of the Holzman-group (Holzman, 1975; Holzman & Levy, 1977) as its starting point, aimed--somewhat optimistically, perhaps--at distinguishing in terms of smooth pursuit behavior, not only between schizophrenics and normals, but also between two psychotic subgroups, viz. schizo-

phrenics and cycloid psychotics. Although the first study (Paper I) did reveal differences between these two subgroups and also between them and a group of normal subjects, Ditchburn´s (1983) comment on that study, that perhaps the most important result was the finding that the patients do track moderately well, seems well founded. Thus, in light of the fact that the patients were seriously ill, may possibly have overreacted in their anxiousness of doing well on the tests, and were under the influence of drugs, the differences between the patients and the normals may seem rather small. The lack of any evidence generally that schizophrenic patients have gross structural brain lesions also makes the obtaining of only small differences here appear plausible enough.

The finding of differences at the macro-level between the two psychotic subgroups seems consistent with certain results from the literature concerning differences between schizophrenics and other psychotic groups. Thus, for example, Matthysse et al. (1986; see also Lipton et al., 1983) reported that some 50% to 85% of hospitalized schizophrenics show disordered tracking, in contrast with some 20% to 50% of those patients with major affective disorders (mainly bipolar psychotics).

Results of the two initial investigations (Papers I-II) showing cycloid psychotics to in many cases display even worse tracking performance than schizophrenics may appear somewhat unexpected, however. Thus, cycloid psychotics are generally regarded as having a rather benign outcome to their illness as compared with schizophrenics. The finding reported in Paper II of some of the cycloid psychotics showing higher and others lower performance than that of the schizophrenics when repeated testing took place suggests the occurrence of phasic changes in cycloid psychotics, making the aforementioned results more plausible. In accordance with the theoretical views of Matthysse et al. (1986), it may be argued that deviant eye-tracking in cycloid psychotics reflects variability of a state-related sort. Thus, the findings reported in Papers I and II do not necessarily oppose the view of regarding eye tracking dysfunction as being a trait variable characteristic of

schizophrenia. There is some possibility here, in fact, of regarding schizophrenia and disturbed eye tracking as independent expressions of a latent trait (cf. Matthysse et al., Op.cit.). The results obtained emphasize the need of employing repeated testing when eye tracking measures are used to classify psychotic patients. Perris (1974), although not considering the use of eye tracking measures as such, has emphasized the importance of examining day-to-day variation before the differential diagnosis of cycloid psychosis versus schizophrenia is arrived at.

As to drugs, several lines of evidence suggest that the high incidence of deviant pursuit in schizophrenics cannot be accounted for by the effects of neuroleptics (cf. Holzman, 1985). Thus, Holzman argues that the Diefendorf and Dodge (1908) study predated the introduction of phenothiazenes with about 45 years and that, consequently, neuroleptics cannot account for their finding. It may be argued, however, that other drugs might be responsible for the deviant eye tracking of the dementia praecox-patients of that period. The first barbiturate, dietylbarbituric acid or barbital, was introduced into medical use already in 1903 (Harvey, 1975), five years prior to the publication of the Diefendorf and Dodge study. It, not to mention alcohol, opiates, and belladonna, could have been used to calm the patients. As evident in the curves reproduced by Diefendorf and Dodge, the smooth pursuit records of the schizophrenic patients they tested tend to show a clear saccadation, typical for patients under the influence of sedatives or alcohol.

In recent literature, some evidence has been provided that lithium-carbonate, as given to patients with affective disorders, impairs smooth pursuit (Levy, Dorus, Shaughnessy, Yasillo, Pandey, Janicak, Gibbons, Gaviria, & Davis, 1985). Although two of the cycloid psychotics and one of the manic-depressive psychotics reported on in Paper II were receiving lithium, none of the nine cycloid psychotics of Paper I were on that drug. Thus, the fact that two of the cycloid psychotics reported on in Paper II were being administered lithium, does not appear to explain the deviant eye tracking found for

the cycloid psychotics in that study, since in Paper I the cycloid psychotics showed even poorer performance than the schizophrenics.

Although Levy et al. (1985) measured ion concentrations of lithium in the patients they studied, information concerning serum concentration of the various drugs administered to patients is lacking in most eye-tracking studies of medicated patients, and indeed seems much needed.

Effects of ethanol on eye tracking seem to have previously been largely confined to healthy young people (e.g., Wilkinson et al., 1974; Guedry et al., 1975; Levy et al., 1981), whereas repeated studies of alcohol abusers, such as reported in Papers III and IV, have somewhat incomprehensively been lacking. As the present results indicate, pursuit behavior of alcohol abusers in a condition of acute ethanol intoxication shows typical saccadation, quite as one could expect on the basis of earlier reports. These effects of ethanol, which appeared to persist for about 24 hours after a period of drinking ended, were replaced by relatively smooth tracking if abstinence continued. It might be expected that, among ethanol´s long-term effects on the central nervous system of alcohol abusers, one would find some disturbance in macrolevel tracking, also when subjects were not directly under the influence of ethanol. There is indeed some evidence from the literature of a positive relationship being found between continuous drinking and brain dysfunction (see, for example, Berglund & Leijonquist, 1978). Some of the studies of long-term reversibility of cerebral dysfunction in persons with alcohol abuse may be interpreted as providing evidence that reduction in drinking results in psychometrically ascertainable improvement, at least as regards spatial problem-solving abilities (cf. Berglund, Leijonquist, & Hörlén, 1977). The great majority of the alcohol abusers studied in Papers III-V were not over the age of 50. Since in the literature there is evidence of the pursuit eye movement system degenerating with age, and since there is the possibility that long-term ethanol abuse results in an acceleration of aging in subjects above the age of 50 (cf. Berglund, 1985), eye tracking data seem to offer considerable potential as a marker of such alcohol-related degenerative processes (cf.

Hartje et al., 1978).

The observation of benzodiazepine medication in the alcohol abusers tending to lower deviation area seems congruent with the finding of Rothenberg and Selhoe (1981) that this drug reduces pursuit gain. However, Holzman et al. (1975) report single doses of diazepam not to affect smooth pursuit in a group of normals they studied.

Microtremor rate is a measure that seems to possess considerable potential for distinguishing between normals, psychotics and alcohol abusers. However, it also seems to be extremely sensitive as to instrumentation, so that results may not generalize well from one study to another if the equipment used is even slightly different. Thus, for example, in Papers II and III, in which psychotics and alcohol abusers, respectively, were tested and their microtremor results compared with those of the normals tested in Paper I, the amplifier system employed differed from that in Paper I. The partly inter-study comparisons of microtremor rate carried out in Paper III indicated alcohol abusers to have a higher microtremor rate than normals. In contrast, in Study II of Paper IV, where all comparisons--here between schizophrenics, normals and alcohol abusers--were intra-study and the equipment employed was the same for all the subjects, normals were found to have a higher microtremor rate than alcohol abusers. Since in other respects results for Papers I-IV are consistent with one another, it can be concluded that normals indeed tend to have a higher microtremor rate than alcohol abusers, and that hebephrenic schizophrenics tend to have a higher microtremor rate than normals.

It may be conjectured that the low level of microtremor rate obtained for relatively young alcohol abusers (Paper IV) may point to an early and chronic central nervous system disturbance in such subjects, a disturbance which seems less reversible than the acute disturbances affecting the macrolevel measures of tracking. The possible site or sites in the brain chronically affected by ethanol can only be speculated on, although it could seem likely that some disturbance of cerebellar integration in the flocculonodular lobe or

of the transmission of vestibular information is involved (cf. Levy et al., 1981). Furthermore, long-term exposure of animals to ethanol seems generally to produce an increase in the cholesterol-to-lipid ratio in neuronal membranes, producing a "stiffer membrane" (Chin, Parsons, & Goldstein, 1978). Different properties of the neuronal membrane may influence information-processing in the central nervous system and be responsible for the low level of activity at the microtremor level in the chronic alcohol abusers. Although homeostatic adaptive changes may develop in response to the chronic intake of alcohol (Kalant & Woo, 1981), the "stiffer" low-capacitance of the membrane, which chronic alcohol abuse produces, appears to result in the membrane being more "fluid" and of higher capacitance following acute alcohol consumption (Durand & Carlen, 1985). The rise in microtremor rate in acutely intoxicated subjects can be tentatively seen as expressing such membrane effects. Likewise, the relatively good tracking of alcohol abusers, despite their low microtremor rate, may be interpreted as being based on active long-term homeostatic changes in cellular physiology taking place in response to the chronic intake of ethanol, this tending to partly counteract the functional deficits which the chronic ethanol intake has produced. These changes may, as already suggested, put greater strain on the information-processing capacity in some other portion, or at some other level, of the central nervous system.

It can be hypothesized that, in normals generally, miniature eye movements (tremor, microsaccades, ocular drift) function together in maintaining lower level trajectory control. If this lower level of control cannot be optimized because of limitations in information processing capacity, higher levels of control may become involved, the solutions thus attempted resulting in sub-optimal trajectories. This, it can be argued, may be the case in alcohol abusers for whom the decrease in activity at the miniature level is compensated for by saccadic activity at a somewhat higher level, as apparently exemplified by the particularly high number of V7-deviations in the sober alcohol abuser considered in Study II of Paper IV.

The relatively low level of activity at the microtremor level in the alcohol abusers who were not acutely intoxicated need not conflict with the view that such activity plays an important part in normal vision. The existence of adaptive resources on both lower and higher levels may shed light upon the important question of whether the saccadic and smooth tracking systems are independent, and may suggest an interaction of velocity and position information to take place, not only partly at higher and partly at lower levels, but also between such levels. Saccadic suppression, which it can be suggested may influence activity at higher and lower levels differently, may be one such inter-level link. The presence of the macro squarewave phenomenon in some of the alcohol abusers when sober may be seen to reflect alcohol-induced shifts in mechanisms responsible for various activities, or in the levels at which they occur, with a corresponding overload and need for the suppression of information.

This macro squarewave phenomenon and the low microtremor rate in the not acutely intoxicated alcohol abusers seem congruent with the report by Feldon and Langston (1977) of a presenile dementia patient who, during fixation, demonstrated frequent squarewaves with a mean amplitude of 4.5 degrees and was totally lacking in microsaccades. Those authors speculated that squarewaves represent greatly enlarged microsaccades.

The relatively high level of microtremor rate the present author found in some of the schizophrenic subjects may possibly reflect the neural activity of a pathologically noisy vestibular apparatus, in line with the view of Wertheim, van Gelder, Lautin, Peselow, and Cohen (1985), who argue that a high level of neural noise emanating there seems to partly explain the impairments of smooth pursuit in schizophrenics. More specifically, those authors suggest that such noisy activity in the vestibular apparatus elevates the threshold for visual perception of movement, causing large retinal errors and compensatory "catch-up" saccades to occur. At the same time, the present author´s results indicating that, under more attention demanding conditions schizophrenics´ microtremor rate tends to increase and their

macrolevel tracking performance to improve, seems to point toward a positive relationship between increased attention and high microtremor rate. Thus, a high microtremor rate may perhaps, depending upon the circumstances, be connected with either an impairment or an enhancement of eye tracking performance, though the situationally induced enhancement of performance under conditions of increased attention appears to represent the more general effect.

At the same time it might be argued, as regards both the microtremor phenomena generally and the poor macro-level tracking of psychotics, that electro-oculographic recordings give rise to measurement errors which might make such results artifactual. Spohn, Coyne, Lacoursiere, Mazur, and Hayes (1985), for example, speak of subtle movement artifacts, based on such factors as neuroleptic dosage, tardive dyskinesia and electrode placement. Those authors indicate that studies using corneal-reflection or infrared recording methods may be needed to rule out such a muscle-potential hypothesis. The results of Feldon and Langston just referred to, which seem quite in line with those for the alcohol abusers in the present studies, were in fact obtained by the simultaneous use of electro-oculography and a highly sensitive infrared eye tracker.

According to Zee and Robinson (1979), the burst cells are fired by motor error signals created by a) continous determination of the difference between desired eye position and b) the central nervous system´s best estimate of actual eye position, which local feedback of the output of the integrator to the burst cells provides. It may be argued that, under more attention demanding conditions, heightened demands regarding desired eye position increase position error and thus the firing rate of the burst cells.

The characteristics observed during the more attention demanding conditions, of an increase in microtremor rate and in the energy contained in the higher (25 Hz-50 Hz) as compared with the lower (<25 Hz) frequency bands, the latter change revealed by spectrographic analysis, can be interpreted as reflective of an increase in miniature eye movement activity in order to

avoid color fusion. Such an interpretation can be seen as compatible with the results of fixation experiments reported by Clowes (1962). Using coloured stimuli with only small differences in luminance, that author noted a marked increase in microsaccades during attempts to suppress the colour fusion phenomenon.

Evidence from neurophysiological studies of monkeys, on the other hand, indicates eye velocity during a saccade to be correlated, not with the firing rate of individual burst cells, but with differences in firing between ipsilateral and contralateral neurons (Gisbergen & Robinson, 1977). Such reciprocal innervation may give rise to an increase in burst neuron discharge rate in a situation involving conflicting cognitive strategies. Thus, the increase in microtremor rate under the more attention demanding conditions of not only tracking the stimulus but also having to react as fast as possible to change in stimulus color, may possibly be based in part on such an increase in burst neuron discharge in a situation with conflicting cognitive strategies.

At the same time, the findings here indicating that under the more attention demanding conditions macrolevel performance tends to improve in terms of noise/signal ratio and deviation area, but concomitantly that activity on the microtremor level tends to increase, may fuel the hypothesis that tracking deficits are not mere correlates of some particular genetic condition, as for example Holzman, Kringlen, Levy, Proctor, Haberman, and Yasillo (1977) and Matthysse et al. (1986) seem to indicate. In view of the evidence obtained in the present studies, it may be argued, in line with Rosenberg (1981), that eye movements themselves are causally involved in psychotic symptomatology (and, as the present results seem to suggest, in alcoholic symptomatology as well) and that poor tracking constitutes a handicap which may make psychosis (or alcohol abuse) "more probable but not inevitable" (Ibid. p. 674). Thus, it may be argued that one way for alcohol abusers to overcome the cognitive handicap of reduced microtremor level activity might be the use of alcohol, where the possibility of thus temporarily overcoming the handicap might at least partly explain the abstinence problems experienced by the

alcohol abuser.

The failure of some of the psychotics to perform better under the more attention-demanding condition (as illustrated in Figure 2 of Paper II) may be indicative of these patients being more disturbed than those who show improvement in eye tracking performance under such conditions.

In normals too, the effect of mental activity on eye movements is clearly evidenced by the subject who, though highly stressed, achieved high macro-level performance, at the apparent cost of microtremor rate increasing dramatically during testing. This behavior--in what appeared to be a typically Type A individual (see Jenkins, Rosenman, & Zyzanski, 1974)--may illustrate the possible contribution of eye tracking parameters to a greater specificity of Type A measures. In a recent study, Rhodewalt and O'Keeffe (1986), employing an Embedded Figures Test and a size estimation task, conclude that field-dependent Type A's are the most hypervigilant but that field-independent Type B's tend to be the next most hypervigilant. Such conclusions seem provocative enough to merit further studies assessing the eye tracking performance of Type A and B subjects. Of considerable interest in this context are the results of Siever et al (1982) showing that subjects with impaired smooth pursuit tracking, which was found in about 5% of the nonpsychiatric patients they studied, were characterized in particular by social inversion as measured by the Minnesota Multiphasic Personality Inventory (MMPI).

In the experiments reported in the present series of studies the target stimuli involved periodic waveforms of constant velocity and duration. According to Holzman (1985), the various target forms (sinusoidal, triangular, circular) and target velocities (from 0.2 Hz to 1 Hz) yield highly similar results in the sense of the eye tracking of psychotic patients being poorer than that of nonpsychotic patients and normals. It may be argued, however, that use of target stimuli of unpredictable waveform may be more valid for studying the quality of smooth pursuit eye tracking (cf. Bahill, Iandolo, & Troost, 1980) since, the more predictable a stimulus is, the less a subject

needs to maintain attention while following it. In ongoing experiments the present author (Andersson, in preparation) is employing predictable as well as unpredictable targets, with and without the extra vigilance task of reacting to a change in color, to study the limits and capabilities of smooth pursuit tracking in normals and in various clinical groups.

SUMMARY

An electro-oculographic technique for the computerized study of the horizontal eye tracking performance of normal and various psychologically abnormal groups, in particular alcohol abusers and certain types of psychotic patients, was employed, the target stimuli involving periodic waveforms of constant velocity and duration. A number of quantitative measures of eye tracking performance of possible relevance in comparing these groups were developed and were used to explore various aspects of the disorders involved and to investigate the role of attention in eye tracking performance. The results of a series of studies, reported in five separate papers, were interpreted as suggesting that the distinction between schizophrenics and cycloid psychotics is a meaningful one, that eye tracking measures can be useful in distinguishing between the two groups, and that the mechanisms involved in eye tracking deficiences of psychotics and alcohol abusers differ. Macro square-wave jerks were found to be prominent in alcohol abusers not acutely intoxicated. Microtremor level phenomena, studied by means of spectrography, appeared to possess considerable potential for distinguishing between normals, psychotics and alcohol abusers, alcohol abusers not acutely intoxicated tending to show a lower and hebephrenic schizophrenics a higher microtremor rate than normals. Under more attention demanding conditions, macrolevel performance as measured in terms of noise/signal ratio was found to improve for all major subject groups, and microtremor level activity to increase. The results of employing an extended program for identifying the occurrence of various types of deviations in eye tracking performance suggested a multi-dimensional analysis including the parallel use of both global and more

specific measures, to offer considerable potential for studying somatic and attentional correlates of eye tracking. The possible neural mechanisms basic to the results obtained are discussed.

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APPENDIX: Papers I–V

III.5 Smooth Pursuit Eye Movements and Attention in Schizophrenia and Cycloid Psychoses

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Early in the 20th century, Diefendorf and Dodge (1908) reported abnormalities of eye tracking in schizophrenic patients. Using a pendular target and photographing light reflected from the cornea, they noted marked disturbances of tracking both in severe and mild cases of schizophrenia (termed dementia praecox at the time). Among other psychiatric patients that they tested, only those with signs of marked deterioration showed such abnormalities. However, Couch and Fox (1934) argued that, since such tracking disturbances are not limited to schizophrenic patients, disorders of attention may represent the more central phenomenon.

Renewed interest in the smooth-pursuit eye movements of schizophrenics was generated by the work of Holzman, Proctor, and Hughes (1973) and of Holzman, Proctor, Levy, Yasillo, Meltzer, and Hurt (1974). Using electro-oculography to measure changes in corneo-retinal field potential as the eye-tracking of the pendulum was monitored, these authors found tracking to be inferior in schizophrenics as compared with non-schizophrenics and normals. They likewise obtained evidence for a similar dysfunction in a large percentage of close (first-degree) relatives of schizophrenic patients, leading them to argue (Holzman et al., 1974) that the dysfunction concerned represents a genetic marker. Shagass, Amadeo, and Overton (1974) confirmed the results of Holzman et al. (1973) regarding the poorer pendulum tracking performance of schizophrenics than of non-psychiatric patients and normals, but found tracking to be inferior in affective psychotics as well. Further work of Holzman and his co-workers (e.g., Holzman & Levy, 1977) suggested disorders of smooth pursuit eye movement to be associated, not only with the pathological conditions named, but also with a variety of

functional psychoses and of central nervous disorders. They interpreted the tracking dysfunction to be inadequate cognitive centering which occurred despite a desire to perform the task.

Both Holzman et al. (1974) and Shagass et al. (1974) reported a lack of success in attempts to improve eye tracking performance through alerting-instructions. However, Shagass, Roemer, and Amadeo (1976) found that requiring a subject to read numbers situated on the oscillating target improved performance considerably, both for patients and for non-patients, though the differences between the two groups were not abolished in this way.

The studies of Holzman et al. (1973, 1974) and of Shagass et al. (1974, 1976) involved both the qualitative assessment of tracking performance and the recording of quantitative aspects, where the number of velocity arrests (seen as an index of the degree to which eye speed departs from target speed) represents a measure of the latter type. Details of both forms of approach have been criticized, for example by Troost, Daroff, and Dell'Osso (1974), Acker and Toone (1978), and Lindsey, Holzman, Haberman, and Yasillo (1978). The latter recommended the natural logarithm of the signal/noise ratio (ln S/N), obtained from the harmonic regression of digitized and standardized eye movement data, as being more relevant than the quantitative measure cited above.

The present study aims at comparing the pendular eye tracking performance of two main psychotic inpatient groups: schizophrenics and cycloid psychotics. The latter diagnostic category stems from the work of Leonhard (1957/1979), who describes the condition of cycloid psychosis as displaying a phasic course, where recovery after a psychotic episode may be complete. Leonhard emphasizes the importance of correct and early diagnosis of the condition, which can readily be misclassified as schizophrenia and treated inappropriately. At present the diagnosis of cycloid psychosis is widely employed within Scandinavia and several continental European countries whereas in many English-speaking countries, for example, the term cycloid psychosis is not even used and patients of this type tend, due to the similarity of various of their symptoms to those of schizophrenics, to be classified as the latter.

The work cited above on the deficits of pendular eye tracking performance in various psychiatric groups suggested it to be worthwhile to investigate the possibilities of distinguishing between schizophrenics and cycloid psychotics on the basis of measures of eye-tracking performance, which might ultimately be useful in a battery of measures aimed at the early diagnosis of cycloid psychotics. To this end a number of quantitative measures of possible relevance were selected. The pendular stimulus, which traditionally has consisted of a bob-and-string arrangement, is represented here by an electronic pendulum of constant, controllable speed. In order to

investigate the possible role of attention in tracking performance, one of the two electronic pendulae utilized involves the moving light spot changing from the original color to a second color at irregular intervals.

METHOD

Recording Procedure

Each of the two electronic pendulae consisted of a string of 70 light diodes mounted in a straight line 38.5 cm in length, behind a vertical plexiglass plate. Through each diode in succession lighting up for a brief interval, and the succession reversing when the end of the string of diodes was reached, an illusion of continous pendulum-like movement was produced. The length of a cycle was 2.5 sec. Each of the diodes was controlled by a timer.

The one pendulum, termed the *sinusiodal pendulum,* displayed movement of a sinusoidal character. The other, termed the *saw-tooth pendulum,* involved the light instead "moving" at a constant speed, so that a graph of the movements back and forth described a (straight-sided) saw-tooth curve. The latter pendulum was equipped with a special type of light diode that could light up with either red or green light, the pendulum being programmed so that the moving spot was red most of the time but became green for short irregularly introduced intervals.

Subjects were seated 0.5 m from the pendulum, with head movement restrained by a chin support. Silver-silver chloride electrodes were placed on the outer canthi of both eyes, and a ground electrode was attached to the middle of the forehead. This electrode placement aimed at minimizing the appearance of blinks on the recordings. Eye movements were registered in the AC mode, using mingograph (M 81, Siemens-Elema, with a paper speed of 10 mm/sec) for quick visual inspection purposes and allowing the preamplifier of the mingograph to drive a Tandberg (TIR) FM tape recorder operating at a 3¾ IPS. The preamplifier was RC-coupled to balance out DC offset voltage, with a high pass filter (time constancy 2.5 sec) and a low pass filter (cut-off frequency 30 Hertz) employed for noise reduction. Calibration was carried out, just prior to the start of the task or task series for each of the two types of pendulae, through having the subject shift his gaze a number of times between the middlepoint of the pendulum and the two endpoints.

The general instructions for subjects were to follow with their eyes the movements of the pendulum. For half the subjects the task with the sinusoidal pendulum was presented first and with the saw-tooth pendulum thereafter, and for half the subjects the order was reversed. The total length of time which the pendulum was to be tracked was 60 sec for the sinusoidal

pendulum and 300 sec for the saw-tooth pendulum. Subjects rested for at least 60 seconds while the one pendulum was being replaced by the other (slightly longer in a few cases due to practical considerations), instructions concerning the task that was to follow being given during this period.

Whereas the sinusoidal pendulum task involved a single (60 sec) tracking period, the saw-tooth pendulum task comprised three different tracking periods. In the first tracking period the "moving" light was red the entire time (60 sec). In the second period, which involved 180 sec of tracking and followed a 60 sec pause during which additional instructions were given, the stimulus color changed temporarily from red to green at irregular intervals. Here the subjects were instructed to press a button each time the light changed to green. The segments of the pendular movement in which the light was green, though irregularly occurring, always comprised ¼ of a total "swing" of the pendulum. Both the pressings of the button and the onset of the green segments were recorded on the mingograph, making it possible to register the times between the onset of the green stimulus and the occurrence of the button-pressing response, as well as the incidence of misses (failure to press the button when it should have been pressed) and false alarms (pressing the button at an inappropriate time). The third tracking period, which was 60 sec in length and followed a 30-sec pause, involved (just as did the first a red pendular stimulus only.

Subjects

Twenty-seven psychiatric patients admitted to the research clinic of St. Lars Psychiatric Hospital of the University of Lund for short-term therapy, as well as four non-patient controls recruited from the clinic staff, were tested. All were informed of the nature of the testing procedure and gave informed consent. The patients were a subsample of the inpatients available during a 3-month period of testing. Only patients who were judged as testable by the staff and personnel, showed no signs of organic brain disease, and had not undergone electric shock therapy for at least the previous three months were tested. Since diagnostic information was not complete at the time of testing and since a certain homogeneity of groups was aimed at, only those patients with the diagnosis of either schizophrenia or cycloid psychosis were included in the final sample of 22 patients employed in the present analysis. The sample obtained in this manner consisted of 13 schizophrenics—of which four were of a hebephrenic type (subjects 18, 19, 26, and 27), three of a paranoid (subjects 02, 05, and 11), and two of a catatonic type (subjects 14 and 15), as well as one each of the simple (subject 07), the residual (subject 08), the schizo-affective (subject 28) and the chronic undifferentiated (subject 23) types—and of 9 cycloid psychotics. As to clinical observations at the time of testing in the case of the cycloid psychotics, a marked difference was

found between the cycloid psychotics 06, 17, 20, and 25, who all were described as hyperactive and the other cycloid psychotic patients, who all were described as more or less inhibited. Of the patients represented here, 9 were men and 13 women; all of the normal subjects were men. The mean age was 29.7 years for the schizophrenics (s.d. = 10.2), 27.5 years for the cycloid psychotics (s.d. = 6.9), and 29.0 years for the normals (s.d. = 5.1). All subjects had completed at least nine years of formal education. All of the patients were receiving neuroleptics at the time of testing (phenothiazine derivates or related substances). No neuroleptic or antipsychotic medication was being administered to any of the normal subjects.

Measures Obtained

Processing of the data from any given subject was carried out for each of five different 30-sec segments of the total tracking task separately, each such 30-sec segment comprising 12 cycles (or slightly more than this) of the pendulum. What is called Period 1 represents the initial 30 seconds of tracking with the sinusoidal pendulum, whereas Periods 2–5 involve successive portions of the saw-tooth pendulum task—Period 2 representing the initial 30 seconds of the first of the two red-light-only tasks, Period 3 the initial 30 seconds of the red-and-green-light tracking tasks, Period 4 a 39-sec segment of the latter task commencing 90 seconds after the end of Period 3, and Period 5 the initial 30 seconds of the second red-light-only tracking task. Since the sinusoidal pendulum was presented at the beginning for half of the subjects and at the end for the other half, Period 1 can appear in either position.

The tape-recorded signals from any given period were digitized by an ABC 80 computer at a rate of 8,200 sampling points for the 30 seconds involved. The data were saved on floppy disc and transmitted by the ABC 80 to a Univac 110/80 system at the Lund University Computer Center, where they were stored, with one file being devoted to each set of 8,200 sampling points, the value for each sampling point being in terms of the electrical voltage (V) measured at the respective point in time. Missing data (less than 5% of the total) were supplied as estimates based on the existing values.

The first step in processing these data so as to obtain summary measures indicative of a subject's tracking performance during a given period was to compute eye position P from V through solving the differential equation $dV/dt = a \cdot dP/dt - b \cdot V$, where dV/dt represents change in V over time. The validity of the measure thus obtained is based on the assumption that the value of P is always the same for the comparable point in any two cycles, and that the mean for the P values as a whole (where these can take on both positive and negative values) is 0. However, drift in the measurement equipment can occur, which can result in parts of the overall curve

sagging under the mean line (which should be at the 0 level) or arching over it. Therefore, a linear correction was introduced (see the following).

The second processing step was to shorten the 30 sec recording whatever slight degree was required to obtain exactly 12 cycles, and to divide these into three segments of four cycles each. The identification of cycle length here was carried out on the basis of a preliminary Fourier analysis. The linear correction just referred to was then applied to each of the three four-cycle segments separately.

The third processing step was to perform a more thoroughgoing Fourier analysis on the series of corrected values that the previous two steps yielded. A Fourier analysis indicates how and to what degree a periodic curve of a given shape can be described as a sum of sinus functions of successively decreasing periodic length, where the periods involved are 1/1, 1/2, 1/3, 1/4, . . . , etc. of the cyclic function being studied. The sinus functions thus obtained are referred to as the 1st, 2nd, 3rd, 4th, etc. harmonic factors.

Further data processing steps, partly based on the steps just described, yielded the following summary measures of the subject's overall tracking performance during any given period:

1. The *noise/signal ratio* was calculated as the ratio between the sum of the squared amplitudes of the 2nd, 3rd, 4th, 5th, and 6th harmonics, on the one hand, and the squared amplitude of the major wave (1st harmonic) on the other. In the case of a subject's following closely the movements of the pendulum, the noise/signal ratio would be low.

2. The *number of crossings* was the number of times the two curves—i.e., the curve describing the movements of the pendulum and the curve describing the movements of the subject's eyes—crossed each other. For a subject following the movements of the pendulum closely, the number of crossings would be expected to be high.

3. The *deviation area* was the size of the area between the two curves just referred to. If the subject's eyes followed the pendulum closely, the deviation area would be low. This measure is more stable than measures based on the Fourier analysis [i.e., the measures described under (1) and (5)], in the sense that the blink of an eye does not affect this measure very much but can severely disrupt the Fourier analysis within the cycle in which it occurs.

4. The *microtremor rate* was computed as a function of the total distance which the eye traveled and the "effective" distance it covered. The *total distance, d(tot),* here is the sum of all small eye movements as measured through recording the position of the eye at 3.66 msec intervals. The *effective distance, d(eff),* is the sum of the eye movements as measured through recording the eye position at intervals which were nine times larger (33 msec). The portion of the total distance produced by microtremors is assumed to be the difference between the total distance and the effective

distance, i.e. d(tot)–d(eff). Thus, the micro-tremor rate was computed as (d(tot)–d(eff))/d(eff).

5. The *2nd, 3rd, 4th, 5th,* and *6th* harmonics were computed as the ratio of the respective higher harmonic factor (i.e., 2nd, 3rd, 4th, 5th, or 6th harmonic factor) to the 1st harmonic factor. These measures provided a description of the different harmonic components of the subject's wave-like eye movements in following the pendulum. It was also possible to compare the measures thus obtained with ideal values for the measures, i.e., the values the measures would take on if the subject followed the moving light perfectly. The computation of such ideal measures for the saw-tooth pendulum (Periods 2–5) yielded values of 0 for the 2nd harmonic, 0.111 for the 3rd, 0 for the 4th, 0.040 for the 5th, and 0 for the 6th harmonic.

6. The *mean reaction time* (MRT) and the *standard deviation of the mean reaction time* (SDMRT) were the mean and standard deviation, respectively, of the subject's reaction time in pressing the button when the light in the pendulum became green. The two measures were computed for Periods 3 and 4, since only during these periods did the light in the pendulum change. The reaction times in question were measured by inspection of the mingograph record.

7. *Misses* and *false alarms,* likewise obtained for Periods 3 and 4 only, were the number of times in the respective period that the subject failed to press the button when it should have been pressed (miss) or pressed the button when it should not have been pressed (false alarm).

RESULTS

Preliminary analysis of differences in the various measures between the schizophrenic and cycloid psychotic groups revealed apparent group differences, many of which, even if not statistically significant, showed a consistent direction from period to period for the five test periods involved. In order to test the hypothesis that the group differences here were of a general character, the following *within-group rank score* was obtained for each of the measures: the 22 psychiatric subjects were rank ordered, within each of the five periods, in terms of their raw score on the measure in question; for each subject the sum of the ranks thus obtained was formed; subjects were then ranked in terms of this sum, the rank of which is termed the subject's within-group rank score.

For four of the measures mentioned above, such scores yielded significant differences (Mann-Whitney U-test, two-tailed) between the schizophrenic and cycloid psychotic groups. Schizophrenics, compared with cycloid psychotics, were found to have lower *noise/signal ratios* ($p = .004$),

higher *numbers of crossings* ($p = .015$), lower *deviation areas* ($p = .049$) and lower *standard deviations of mean reaction times* ($p < .001$). Thus, schizophrenics appeared to perform better than cycloid psychotics both in eye pursuit movements (first three results) and in reaction time consistency shown under the vigilance-type conditions of needing to press the button whenever the green light appears (last result). In a descriptive sense it could be noted as well that the schizophrenics as a group showed a higher *microtremor rate* than the cycloid psychotics, although this result was not statistically significant ($p = .144$). However, a more detailed analysis of the data, with consideration of the hebephrenic ($n = 4$) subgroup of schizophrenics, indicated hebephrenics to have a higher microtremor rate than non-hebephrenic schizophrenics ($p < .05$) and than cycloid psychotics ($p < .05$). The differences in microtremor rate found here were rather large, one of the hebephrenic patients, for example, showing (during two of the test periods) a microtremor rate that was approximately 2½ times that of the patient of highest microtremor rate within both the non-hebephrenic schizophrenic and the cycloid psychotic group, suggesting possible use of the microtremor rate in a diagnostic context.

The fact that, in the case of the saw-tooth pendulum, the first and last periods (Periods 2 and 5) involved red lights only whereas the two intervening periods (Periods 3 and 4) involved the repeated though irregular interspersion of segments where the lights became green instead of red, provided the basis for two difference scores (*Dif-1* and *Dif-2*), obtained for the variables (1) through (6), i.e., for all of the raw-score measures relating to eye movement performance:

Dif-1, or the difference (2 + 5)–(3 + 4)—where each number refers to the value of the raw-score measure obtained during the respective period—is a measure of the effect on eye-tracking performance of changing from the less attention-demanding conditions (red-light-only) to the more attention demanding (need of pressing the button whenever the lights change from red to green), where a positive score represents an improvement in performance under the more attention-demanding conditions.

Dif-2, or the difference (2 + 3)–(4 + 5), is a measure of the effect of practice, a high score indicating the effect to be positive (learning or facilitation) and a low score indicating it to be negative (fatigue).

Comparing the cycloid psychotic and schizophrenic groups on the difference scores (Dif-1 and Dif-2) obtained for each of the variables described under (1) through (6) above revealed no significant or marked differences between the two groups. For both groups there was a general tendency, as evidenced by positive Dif-1 scores, for eye pursuit performance to improve under the more as compared to the less attention-demanding conditions. Such a tendency could be shown with the Dif-1 scores based on the following measures (the numbers of psychotic, i.e., cycloid psychotic and

schizophrenic, subjects with positive and negative Dif-1 values, respectively, are indicated, as are two-tailed p-values based on χ^2): *noise/signal ratio* (20+, 2−, $p<.001$), *deviation area* (16+, 5−, $p<.02$), *2nd harmonic* (18 +, 4−, $p<.01$) and *4th harmonic* (15+, 6−, $p<.05$). Improvement (+) or deterioration (−) in performance in the case of the harmonics was in relation to the ideal measures described under (5) above. In contrast with the results just cited, a deterioration of performance under the more attention demanding conditions was found with the Dif-1 scores of the *5th harmonic* (6+, 15−, $p<.05$).

The character of the improvement in performance shown by all but the last of the measures here is illustrated in Fig. 1, which presents samples of the eye tracking records of a cycloid psychotic obtained from Periods 2 and 3, respectively. As can be seen, tracking is dramatically improved when the more attention-demanding task of Period 3 is introduced, the saccades found in Period 2 being replaced by what appears at least partly to be normal smooth pursuit.

For only two of the measures mentioned under (1) through (6) did the Dif-2 scores indicate a training effect (improvement in performance in Periods 4 and 5 as compared with Periods 2 and 3), such an effect being evident for the following two measures (the number of psychotic subjects

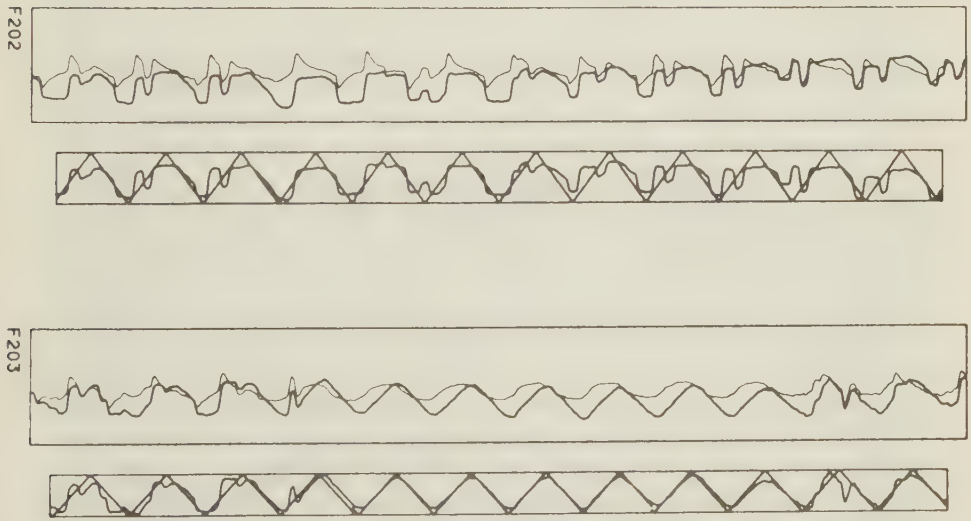

FIG. 1. An example of eye tracking records (subject 20) during Periods 2 and 3 (upper and lower 2 records, respectively). Period 2 = red lights only, Period 3 = intermittent occurence of segments where lights are green. The lower, more abbreviated record from each period has been corrected for drift and shortened to 12 cycles. Light curve = voltage, dark curve = eye position, saw-tooth curve = light (stimulus) position.

showing improvement is labeled with "+" and those showing a worsening with "−", the *p*-values being derived as before): *4th harmonic* (15+, 6−, $p < .05$) and *6th harmonic* (16+, 6−, $p < .05$). On the 5th harmonic, as on the Dif-1 score, a tendency towards worsening was found, although here not significant (6+, 14−, $p > .05$).

In order to explore the feasibility of employing measures of pendular eye-tracking performance as elements in a diagnostic instrument of help in differentiating schizophrenics and cycloid psychotics, a cluster analysis was carried out. A cluster analysis groups individuals according to their similarity in terms of a set of variables. The variables included in the present cluster analysis represented a partly arbitrary selection of measures that were either taken from among, or were based on, those measures in the present study which yielded large or significant differences between the two groups, or revealed significant tendencies common to both groups. Seven such measures were chosen: *noise/signal ratio* (mean of the subject's scores), *number of crossings* (ditto), *deviation area* (ditto), *microtremor rate* (ditto), *standard deviation of mean reaction time* (subject's mean for Periods 3 and 4), *Dif-1 of deviation area,* and *Dif-1 of the 2nd harmonic.*

Not only the 13 schizophrenics and 9 cycloid psychotics but also the 4 normal subjects were included in the cluster analysis, the small size of the normal group not precluding its consideration here since in a cluster analysis each individual subject is compared with all the other subjects. In Table 1, the 26 subjects thus examined are listed by subject number and diagnostic category, the fact of whether a cycloid psychotic was excited (hyperactive) or inhibited at the time of testing also being indicated.

Two steps were carried out preliminary to the actual cluster analysis. The first step was to normalize the measures (over subjects) so as to transform them to a scale between 0 and 1.0 (cf. note to Table 1). Exception to this was taken in the case of subject 20, whose scores on some of the measures were outliers that were dealt with separately, being transformed to values larger than 1.0. The next step was to establish insofar as possible, on the basis of the distribution of the subject's transformed scores, three ranges for each of the measures: a normal, a cycloid psychotic, and a schizophrenic range. This provided the basis for assigning each subject points on a cycloid index and a schizophrenic index, the subject receiving one point on the cycloid index if his or her score on a measure fell within the schizophrenic range. The sums of the cycloid and schizophrenic index points respectively that each subject received in this manner formed the indices, shown in Table 1.

These indices, finally formed the basis for the cluster analysis, the results of which are presented in the form of a dendrogram in Fig. 2. Subjects are grouped in the dendogram in terms of their similarity with one another. Examination of the dendrogram reveals the following: All four of the normal subjects (nos. 29, 30, 31, and 32) fall adjacent to one another, indicative of

TABLE 1
Pendular Eye Tracking Performance Measures (Normalized), Clinical Diagnosis, and Cycloid and Schizophrenic Indices

SUBJECT NUMBER	NOISE/ SIGNAL	NO. OF CROSSINGS	DEVIATION AREA	MICROTREMOR RATE	STD. DEV. REA. TIME	DIF-1 OF DEV. AREA	DIF-1 OF 2ND HARM.	CLIN. DIAG.	CYCL. INDEX	SCHIZ. INDEX
2	.569	.336	.942	.489	.432	.804	.449	S	3	4
4	.659	.303	.641	.289	.713	.817	.426	C-	5	2
5	.559	.447	.401	.345	.551	.316	.000	S	3	2
6	.945	.291	.966	.377	.486	.000	.743	C+	6	1
7	.408	.441	.423	.415	.356	.646	.426	S	1	5
8	.388	.366	.173	.118	.551	.575	.406	S	3	4
9	.591	.453	.421	..316	.778	.563	.495	C-	4	3
11	.530	.526	.230	.248	.551	.495	.461	S	4	2
13	.573	.565	.351	.440	.551	.678	.592	C-	3	4
14	.630	.565	.432	.523	.745	.530	.689	S	3	4
15	.469	.592	.119	.264	.302	.514	.343	S	1	2
17	.616	.225	.960	.346	.486	.256	.437	C+	6	1
18	.729	.718	.503	1.000	.324	.744	.197	S	1	3
19	.876	.492	.803	.614	.799	.767	.615	S	4	3
20	2.500	.240	1.500	.373	1.750	1.000	1.250	C+	7	0
21	.404	.462	.127	.128	.421	.495	.360	C-	1	2
23	.275	.348	.287	.222	.259	.662	.387	S	2	4
24	.729	.450	.484	.427	.583	.392	.670	C-	3	3
25	.663	.216	.951	.256	.475	.571	.459	C+	6	2
26	.551	.520	.718	.887	.389	.705	.488	S	3	4
27	.368	.486	.338	.392	.259	.618	.569	S	1	5
28	.539	.658	.236	.423	.356	.476	.557	S	2	2
29	.476	.862	.021	.435	.454	.564	.360		0	0
30	.524	.550	.209	.397	.259	.413	.306		0	1
31	.521	.405	.302	.232	.356	.522	.313		1	1
32	.512	1.000	.022	.462	.194	.531	.383		0	0

Note. S = schizophrenic, C = cycloid psychotic (+ hyperactive, − inhibited), no clinical diagnosis = normal. Subjects in the normalization group included those listed plus five patients of other diagnosis. Some sources of subject 20 were outliers and were handled separately.

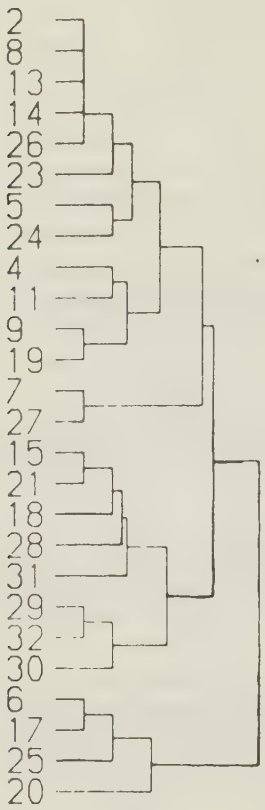

FIG. 2. Dendrogram (cluster analysis). Subject numbers are indicated.

close similarity within the present context (all have cycloid and schizophrenic index values of 0 or 1, as can be seen in Table 1). The hyperactive cycloid psychotics (nos. 6, 17, 20, and 25) form a group of their own (all are higher on the cycloid index than any of the other subjects, with values of 6 and 7, and low on the schizophrenic index, with values of 0, 1 or 2—see Table 1). The schizophrenics and the inhibited cycloid psychotics do not fall in separate groups in the dendrogram, but one can note that the two subjects with the clearest appearing schizophrenic pattern in terms of the eye pursuit performance indices (nos. 7 and 27, with schizophrenic index value of 5 and cycloid index values of 1—cf. Table 1) are both clinically diagnosed as schizophrenics.

The possibility was examined that, despite the failure of the schizophrenic and cycloid indices to effectively distinguish the schizophrenic from the inhibited cycloid psychotic patients via the dendrogram, the use of criterion values for the two indices would enable such a differentiation to be made. On the basis of the distribution of schizophrenic and inhibited cycloid

psychotic patients on the two indices, a combined criterion was established according to which those patients with schizophrenic index values of 4 or more and cycloid index values of 2 or less would be tentatively classified as schizophrenics and the remainder of the patients as cycloid psychotics. Such a combined criterion was found to correctly identify 10 of the 13 schizophrenics and 8 of the 9 cycloid psychotics (cf. Table 1). Similarly, for differentiating between the two cycloid psychotic subgroups, a criterion was determined such that those cycloid psychotics with cycloid index values of 6 or more would tentatively be classified as hyperactive and the rest as inhibited. This criterion placed each of the cycloid psychotics in the correct subgroup. Finally, for differentiating patients from normals, a criterion was selected where subjects with cycloid index values of 1 or less would tentatively be classed as normal. This criterion was also completely successful, since all of the patients had cycloid index values of 3 or more. Thus, in the present study, it is possible, through use of criterion values for the schizophrenic and cycloid indices, both of which were based on pendular eye pursuit performance, to successfully distinguish between schizophrenic, inhibited cycloid psychotic, hyperactive cycloid psychotic and normal subjects in all cases but four.

DISCUSSION

The results just cited support the assumption that the distinction between schizophrenics and cycloid psychotics—largely neglected in the English-language literature—is a meaningful one and that measures of pendular eye tracking performance can be useful in distinguishing between the two groups. Further work is necessary, however, to determine what set of eye pursuit performance measures would be most satisfactory here and to assess in a larger and more representative sample what index-point ranges and criterion values should best be employed. It should be stressed that the present selection of measures for the indices was rather arbitrary and that the groups studies comprised only a small number of subjects. A discussion of possible interpretations of various of the measures considered follows.

Two measures to which objections might be raised are those concerning reaction time. One can note that the task conditions under which reaction time was measured are rather similar to those of the Continuous Performance Test, a test used to demonstrate the improvement that may occur in the vigilance performance of schizophrenics after phenothiazine drugs have been administered (cf. Kornetsky, 1972). Since all of the patients had received phenothiazine drugs or drugs similar to these, and since little is known of the effect of such drugs on the vigilance of cycloid psychotics, the possibility exists that the tendency found for cycloid psychotics to display more varying reaction time than schizophrenics may be artifactual.

A question of obvious interest in connection with such measures as those of noise/signal ratio, number of crossings and deviation area, which indicate tracking deficits of a rather obvious character on the part of the patients (cf. also Holzman et al., 1973, 1974; Holzman & Levy, 1977), is whether the deficits involved reflect central or peripheral disturbances. One can note that when the task was made more complex through instructions being given to attend to shifts in the color of the moving pendulum and to press the button when the color became green, patients' performance on these measures improved. This suggests central disturbances to lie at the basis for the deficits. The view of Holzman et al. (1974) that schizophrenics display a failure of central inhibitory control seems relevant in this connection, particularly since those authors apparently included in the schizophrenic category patients that in the present study would be classed as cycloid psychotics.

In apparent contrast to the measures just named, the patients' performance in terms of the 5th harmonic was found to deteriorate under the more complex conditions. This raises the question of what the higher harmonic measures represent. A possible answer is suggested by a detail of Fig. 1, where it can be noted in the lowermost record (which is for the more complex conditions) that the eye movements of the subject in question fail to continue on all the way to the point where the direction of the pendular movement reverses itself. Such a failure, concerning as it does only a small portion of the pendulum's total swing, could be expected to affect the higher harmonics more than the lower. That such a failure occurs to a greater extent when conditions are complex is perhaps reflective of the cognitive strain the complex conditions involve. As this tentative interpretation of the findings for the 5th harmonic illustrates, the higher harmonics may be reflective of small but meaningful aspects of task performance.

How task performance is affected by microtremor is unclear, as is the origin of microtremor, whether more peripheral (e.g., in the ocular muscles or the retina) or more central. The fact that the hebephrenic schizophrenics displayed a much higher microtremor rate than the other patients suggests at any rate the measure could be useful in differentiating schizophrenic subgroups.

As already emphasized (cf. Leonhard, 1957/1979), means should be sought of identifying cycloid psychotics at an early stage. The present findings suggest that eye tracking performance measures could be useful in this respect to aid clinical diagnosis. Such measures could also be useful in studying the phasic changes occurring in such patients during extended periods of clinical contact.

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EYE TRACKING PERFORMANCE AND ATTENTION IN PSYCHOTIC PATIENTS

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ABSTRACT

The pendular eye tracking performance of a group of psychotic patients (9 schizophrenics, 8 cycloid psychotics and 2 manic-depressive psychotics), tested on two different occasions a week apart, was studied, using electro-oculography. An electronic pendulum involving a light of constant speed was employed, there being two different tasks, a less attention demanding task (red light only) and a more attention demanding task (pressing a button when the light turned to green at short, irregular intervals). Signal/noise ratio, 2nd to 6th harmonics, deviation area and microtremor rate were calculated, as were measures of the effect on these of the attention demands of the task and of the time spent at the task. Schizophrenics were found to differ from the other two psychotic groups in their overall tracking performance, cross validating in part results of an earlier study. Differences here were obtained on the initial test only. This was seen to reflect phasic change or improvement in the cycloid psychotics. There was an overall tendency, as already shown in the earlier investigation, for performance to be better under more attention demanding conditions, certain measures with high reliability. Microtremor appeared rather sensitive to particular aspects of the tracking task.

Since the rediscovery of deviant smooth pursuit eye movements in schizophrenics (Holzman, Proctor and Hughes, 1973), several studies have demonstrated eye tracking to be deviant in schizophrenics as compared with normals and other subjects (e.g., Holzman, Proctor, Levy, Yasillo, Meltzer and Hurt, 1974; Cegalis and Sweeny, 1979). Inferior eye tracking, however, has been reported in other patient-groups as well, for example in affective psychotics (Shagass, Amadeo and Overton, 1974). Interestingly enough, Shagass et al. (op. cit.) found that facilitating attentional effort through the introdution of unsystematic numeric information shown on the oscillating target improved performance considerably, both for patients and non-patients.

An earlier investigation (Andersson, 1983) indicated that schizophrenics (n = 13), cycloid psychotics (n = 9),* and normals (n = 4) could be

*The category of cycloid psychosis stems from the work of Leonhard (1957, 1979), according to whom cycloid psychotics display a phasic course, where recovery after an episode may be complete. Leonhard indicates the condition to be easily misclassified as schizophrenia and treated inappropriately.

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distinguished rather well in terms of pendular eye tracking performance. Results of cluster analysis coupled with the use of criterion values for indices based on such pendular eye tracking measures as noise/signal ratio, deviation area, Fourier harmonics and microtremor yielded correct classifications in all but four cases. Patients' performance was found, for most measures, to be considerably better at a more attention-demanding than at a less attention-demanding eye pursuit movement task.

The present study, involving methodology very similar to that of the earlier investigation, concerned two major questions: (a) whether the results of the earlier investigation could be verified using a different group of subjects, representing a sample of all the testable psychotic patients available at a psychiatric hospital during a given period; (b) whether the results obtained would be reliable in the sense that the findings of two testings a week apart would be the same or similar.

METHOD

Recording procedure

Details of the methods and procedures employed are to be found in Andersson (1983); in the present investigation only the results of one of the two pendulae employed earlier is reported, namely the saw-tooth pendulum, in which the 'moving' light travels at a constant speed. This pendulum has special light diodes which can light up either red or green, the moving spot being red most of the time but becoming green for short irregular intervals. The task involves three periods of tracking. During the first period (60 sec) the target is red. During the second period, in which there are 180 sec of tracking following a 60 sec pause, the stimulus color changes temporarily from red to green at irregular intervals, subjects being instructed to press a button each time the light changes to green; a green segment, when it occurs, comprises 1/4 of the 'swing' of the pendulum in one direction or the other. The third tracking period, 60 sec in length following a 30-sec pause, involves (as did the first) a red pendular stimulus only. In contrast with the earlier investigation (Andersson, 1983) all subjects except those who had been discharged from the hospital prior to the second testing were tested twice, the second testing being approximately one week after the first.

Eye movements were registered in the AC mode with an electrooculographic technique, using a mingograph (a Beckman R-511A Dynograph Recorder). The preamplifier of the mingograph drove a Tandberg (TIR) FM tape recorder operating at a 3 3/4 IPS; it was RC-coupled to balance out DC offset voltage, with a high pass filter (cut-off frequency 0.16 Hz) and a low-pass filter (cut-off frequency 30 Hz) for noise reduction. Calibration was obtained by having the subject shift his gaze several times between the two endpoints of the pendulum.

Subjects

Nineteen psychotic patients remitted to S:t Lars Psychiatric Hospital in Lund for short-term therapy were tested. All were informed of the nature

of the testing procedure and gave their informed consent. The patients were a subsample of those available during a three month period, only patients judged testable by the staff, lacking signs of organic brain disease, and not treated with electric shock therapy during at least the three previous months being tested. The sample consisted of eight cycloid psychotics (4 men, 4 women; mean age 26.6 with S.D. 5.6), two manic-depressive psychotics (both men; ages 27 and 50), and nine schizophrenics (5 men, 4 women; mean age 30.9 with S.D. 9.3). The subcategorization of the schizophrenics was as follows: 4 hebephrenics, 3 paranoids, 1 undifferentiated and 1 non-regressive, the latter according to the criterion of Nyman (1978). The combined cycloid psychotic and manic-depressive psychotic group had a mean age of 29.0 with S.D. 8.9. The mean time of current hospitalization was 8.5 days (S.D. 8.7), there being no notable differences between the three groups in this respect. All subjects had completed at least nine years of formal education. All except one (the non-regressive schizophrenic) were receiving phenothiazine derivates or related substances (derivates of thioxanthene or butyrophenone). In addition, two cycloid psychotics and one manic-depressive psychotic had received lithium citrate; the latter patient and one cycloid psychotic had been given benzodiazepine derivates; also, five cycloid psychotics and two schizophrenics were receiving anticholinergic drugs. The four subjects who were tested only once due to their discharge from the hospital before a second testing could be carried out consisted of two cycloid psychotics, one hebephrenic schizophrenic and the undifferentiated schizophrenic.

Measures obtained

Processing of the data from any given subject followed Andersson (1983) and was carried out for each of four different 30-sec segments of the total tracking task separately, each such 30-sec segment comprising 12 cycles (or slightly more than this) of the pendulum. Periods 1–4 involve successive portions of the pendular task – Period 1 representing the initial 30 seconds of the first of the two red-light-only tasks, Period 2 the initial 30 seconds of the red-and-green-light tracking tasks, Period 3 a 30-sec segment of the latter task commencing 90 seconds after the end of Period 2, and Period 4 the initial 30 seconds of the second red-light-only tracking task. Tape-recorded signals were digitized at a rate of 8,200 sampling points for each 30 second period. Data-processing involved computing eye position P from electrical voltage V at each of the sampling points through solving the differential equation $dV/dt = a \cdot dP/dt - b \cdot V$, where dV/dt represents change in V over time. A correction employed for drift consisted in subtracting from V its mean value within each cycle. Each 30 sec recording was shortened to exactly 12 cycles, a preliminary Fourier analysis being used in identifying cycles here. A more thorough Fourier analysis was also carried out. The following measures were obtained for each of the four periods:

(1) *Signal/noise ratio*. The ratio between the sum of the squared amplitudes of the 2nd, 3rd, 4th, 5th and 6th harmonics, on the other hand, and the

squared amplitude of the major wave (1st harmonic) on the other. For a subject following the movements of the pendulum closely, this measure would be low.

(2) *The 2nd, 3rd, 4th, 5th and 6th harmonics.* the ratio of the respective higher harmonic factor (i.e., 2nd, 3rd, 4th, 5th and 6th harmonic factor) to the 1st harmonic factor. With perfect tracking the values would be 0 for the 2nd harmonic, 0.111 for the 3rd, 0 for the 4th, 0.040 for the 5th and 0 for the 6th harmonic.

(3) *Deviation area.* The area between the two curves describing the movements of the pendulum and of the subject's eyes, respectively. If the subject followed the pendulum closely, this measure would be low.

(4) *Microtremor rate.* (d(tot)-d(eff))/d(eff), where d(tot) represents the total distance and d(eff) the 'effective' distance the eye covered, and where d(tot) and d(eff) represent the sum of all small eye movements as measured through recording eye positions at 3.66 msec intervals, and at intervals nine times larger (33 msec), respectively.

For each such measure, a summary measure of the subject's *overall tracking performance* (*OTP*) during the four periods together was calculated. In addition, two types of difference score, *Dif-1* and *Dif-2*, were obtained for each of the measures (1) to (4) above, following Andersson (1983). *Dif-1*, the difference (1 + 4) (2 + 3), where the numbers here refer to the successive periods, indicates the effect on eye tracking performance of changing from the less attention-demanding conditions (red-light-only) to the more demanding (changing light color). *Dif-2*, the difference (1 + 2)–(3 + 4), represents the effect of practice. Using these summary measures, comparisons were made between the schizophrenic (S) and the cycloid-manic-depressive (CD) groups, the latter group comprising both the cycloid psychotic (C) and the manic-depressive (D) patients. For the fifteen persons tested twice, comparisons were made between A and B for all the above measures. Statistical tests were all two-tailed.

RESULTS

Significant differences between the S and the CD groups were found on two of the overall tracking performance (OTP) measures, in both cases for A only. CD tended here to have more extreme signal/noise ratios ($p < 0.01$, Moses test) and higher deviation area ($p < 0.02$, Mann-Whitney U-test) than S. Similar differences were obtained in comparing S with C. The results for deviation area ($p < 0.05$, Mann-Whitney U-test) concurred with those of the earlier investigation (Andersson, 1983), whereas those for signal/noise ratio concurred only in part. The earlier study had shown signal/noise ratios to be higher for C than for S. Although in the present investigation, the signal/noise ratios of C tended instead toward the two extremes ($p < 0.01$, Moses test), the three subjects with the highest signal/noise ratios (also when the D group is considered) all belong to the C group.

Concerning Dif-1 and Dif-2 scores, no clear differences between the psychotic groups were found, quite in agreement with the results of the earlier investigation. At the same time, these difference scores revealed general tendencies for the psychotic group as a whole in various of the measures:

For signal/noise *ratio*, performance was found to be better generally under more than under less attention-demanding conditions (i.e., Dif-1 scores were predominantly positive), both for A (15 +, 4 −, $p < 0.02$, χ^2 − here as in the following), as in the previous study, and for B (12 +, 3 −, $p < 0.05$). These results appeared reliable, only 2 of 15 subjects showing a different sign (+ or −) on the two occasions tested.

Regarding the Dif-1 scores for the various *harmonics*, performance (assessed relative to the ideal values listed above) was found, for the *4th* harmonic, to be better under the more demanding conditions (14 +, 4 −, $p <$ 0.02, in A; 10 +, 5 −, n.s., in B), whereas for the *5th* harmonic the opposite results were obtained, (5 +, 14 −, $p < 0.05$, in A; 3 +, 12 −, $p < 0.05$, in B). Both results are in agreement with those of the earlier investigation. No consistent or significant tendency could be found for the *2nd* harmonic, as it was in the earlier study, for performance to be better under the more attention demanding conditions. Regarding Dif-2 scores, no significance was obtained for the different harmonics, although a non-significant tendency toward improvement over time was found for the *4th* harmonic, both for A and B, in weak agreement with the significant tendency of this sort obtained in the previous study.

Concerning *deviation area*, no significant tendency was found, as it had been in the earlier investigation, for performance to be better under the more attention demanding conditions, although results in A did point in this direction (13 +, 6 −, n.s.). Also, comparing A and B, results for the individual subjects appear to be reliable, 13 of the 15 subjects who were tested on both occasions showing the same type of tendency during A and B. (7 + +, 6 − −). All four of the subjects who were discharged from the hospital after A showed better performance under the more attention demanding conditions.

The general finding of eye tracking performance improving under the more attention demanding conditions is illustrated by the curves (of a staircase form in Periods 1 and 4) obtained for a cycloid psychotic (Fig. 1), whereas the less usual finding of performance deteriorating under the more attention demanding conditions is illustrated by the curves of a hebephrenic schizophrenic (Fig. 2).

Microtremor rate tended to be higher under the more attention demanding conditions (17 +, 2 −, $p < 0.001$, for A; 9 +, 6 −, n.s., for B). Dif-2 scores showed microtremor rate to decrease over time, both in A (14 −, 5 +, $p <$ 0.05) and in B (12 −, 3 +, $p < 0.05$).

DISCUSSION

Results of the present study provide cross-validational support for many of the findings of the earlier investigation (Andersson, 1983). Both deviation

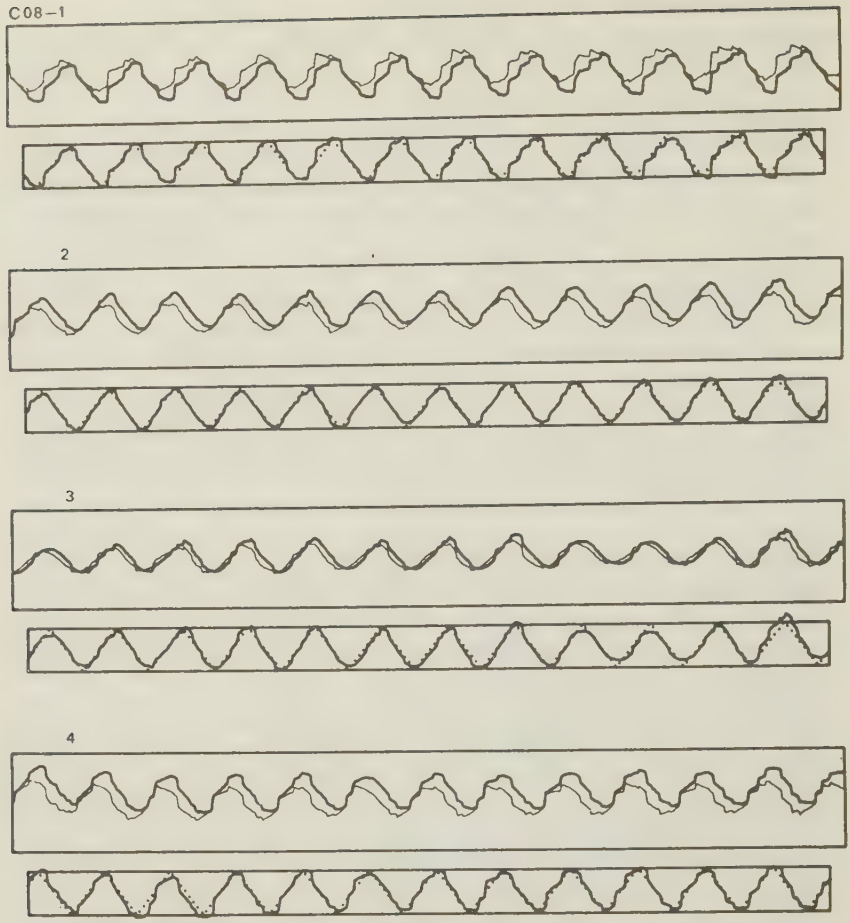

Fig. 1. Eye-tracking pattern in a cycloid psychotic during Periods 1–4. Periods 1 and 4 = red light only, Periods 2 and 3 = intermittent occurrence of segments where the light is green. The lower, more abbreviated record from each period has been corrected for drift and shortened to 12 cycles. Thin curve = initially registered voltage; thick curve = eye position; dotted, saw-tooth curve = stimulus (light) position. An improvement in eye tracking performance under the more attention-demanding conditions (Periods 2 and 3) is evident.

area and signal/noise ratio differentiated clearly enough between cycloid psychotics (or the combined group of these and manic-depressive psychotics) and schizophrenics. The signal/noise ratio measure appeared somewhat enigmatic, since in the previous investigation cycloid psychotics showed poorer performance, whereas here they showed more extreme performance (high or low), as compared with schizophrenics. The differentiation found on either measure was obtained only on the first test (A). This may be due, as the work of Leonhard (1957, 1979) would suggest, to phasic changes on the part of the cycloid psychotics. The phasic change here may have been

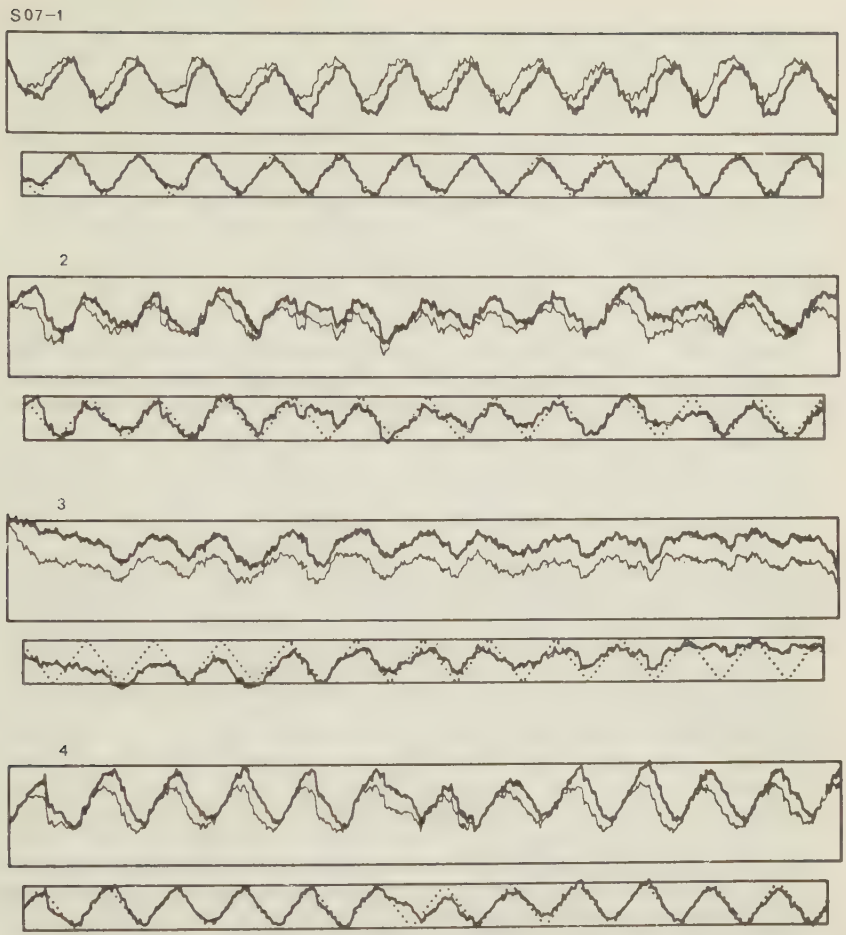

Fig. 2. Jagged eye tracking pattern in a schizophrenic patient (cf. Fig. 1). A deterioration in eye tracking performance under the more attention-demanding conditions (Periods 2 and 3) is evident.

largely that of improvement, since in terms of deviation area the cycloid psychotics shifted between A and B from being worse in performance than schizophrenics to not differing from them. A crucial investigation in future work would involve following changes in the eye tracking performance of cycloid psychotics and schizophrenics during a more extended period, with shorter intervals between testing.

No differentiation between the psychotic groups could be shown as regards the effect of variations in the attention demands of the task or in the time spent at the task. Scores indicative of the former (Dif-1 scores) showed a high degree of reliability from the first to the second test occasion for the deviation area and signal/noise ratio measures. This accords roughly with findings of Holzman et al. (1973) and Shagass et al. (1974), who with other

eye-tracking measures than those employed here and a longer period of time between testings (2 months and 6 months, respectively) reported high test-retest reliability in the patients they examined. Generally speaking, patients in the present investigation showed better performance under the more attention demanding conditions. The lone exception to this, here as in the earlier study, was in the case of the 5th harmonic. As suggested in Andersson (1983), superior performance there under the less attention demanding conditions may be reflective of small but meaningful aspects of task performance. The question of whether psychotic patients differ from normal subjects in the effect of attention demands or fatique upon performance is not touched upon by the present results and should be examined.

Microtremor rate was found to increase as cognitive strain increased, but nevertheless to decrease over time. Whatever may lie at the basis for this, the results suggest that microtremor rate may be quite sensitive to various aspects of the tracking task.

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The present research was supported by the Swedish Council for Social Science Research and by the Medical Faculty of the University of Lund. The author is grateful to Robert Goldsmith for his helpful comments, to Birgitta Rorsman for her encouragement and advice and to Göran Franzén and Mårten Gerle for their generosity in placing the facilities of S:t Lars Psychiatric Hospital at my disposal.

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EYE TRACKING PERFORMANCE AND ATTENTION IN ALCOHOL ABUSERS AND PSYCHOTIC PATIENTS

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Pendular eye tracking performance of a group (n=20) of alcohol abusers was studied by means of electrooculography, retests being made on 15 of the patients within a three-month period. An electronic pendulum involving a "moving" light of constant speed was employed, there being two different tasks, a less attention demanding task (following a red light only) and a more attention demanding one (besides following the light, having to press a button when the light turned green, at short, irregular intervals). The results were compared with those of psychiatric patients (n = 19) and normals (n=4) whom the author studied earlier. Although it was not possible to distinguish psychotic patients from alcohol abusers on the basis of overall measures of noise/signal ratio and deviation area, microtremor was found to be categorically higher in psychotic patients than in alcohol abusers. Since no differences were observed between psychotic patients and alcohol abusers in patterns of response as cognitive strain increased or over time during a testing session, these aspects of the tracking tasks did not seem to account for the very large differences found in microtremor, leaving the possibility open that disturbance of a central nature was found in the psychotic patients. During eye tracking, macro squarewave jerks were significantly more frequent in alcohol abusers than in psychiatric patients. It is suggested that in alcohol abusers this phenomenon represents a defect in a saccadic pulse generator, triggered by an unwanted supranuclear command signal.

Alcohol in moderate amounts has been reported earlier to impair the two basic types of conjugate eye movements used for tracking a moving target, namely those of the saccadic and the smooth pursuit systems (Drischel, 1968; Franck and Kuhle, 1970; Wilkinson, Kime and Purnell, 1974; Flom, Brown, Adams and Jones, 1976; Guedry, Gilson, Schroeder and Collins, 1975; Umeda and Sakata, 1978; Baloh, Sharma, Moskowitz and Griffith, 1979; Levy, Lipton and Holzman, 1981; Lehtinen, Nyrke, Lang, Pakkanen and Keskinen, 1982). In all of these studies, however, the influences of alcohol on pursuit movements was examined using healthy young people as subjects. In the present study, therefore, the aim was to investigate the effects of alcohol on smooth pursuit in a group of alcohol abusers. Although it is generally believed that even moderate doses of ethanol disrupt smooth pursuit and result in saccadic pursuit, due to compensation for a reduced ability of the eyes to maintain foveation, little is known of the smooth pursuit capacity in excessive users of alcohol.

Levy et al. (1981) studied pendular eye-tracking performance in a group of healthy young non-alcoholics before and after administration of single doses of alcohol. They found that a number-reading task they presented simultaneously, one which Shagass, Amadeo and Overton (1974) and Holzman, Levy and Proctor (1976) reported as reducing eye-tracking impairment in schizophrenics, tended to alleviate the alcohol-induced disruption of eye-tracking performance. In the

number-tracking task, arabic numerals were displayed on the pendulum, with different numbers appearing as the pendulum oscillated, the subject being instructed to read the numbers silently while tracking the pendulum. The authors attributed the effect of the number-reading task to its facilitating the visual fixation mechanism, which they considered to have been disrupted by alcohol. At the same time, Shagass et al. (op. cit.) and Holzman et al (op. cit.) suggested that the number reading task only partially compensates for psychosis-induced disruption of eye-tracking performance, the magnitude of the "normalizing effect" varying with the extent of the impairment. This made it appear of interest in the present study to explore the effects of attentional manipulations on the disruption of smooth pursuit performance in chronic alcoholics, one hypothesis being that the central nervous system dysfunction which alcohol produces is more pronounced in these subjects.

In earlier investigations, the present author (Andersson, 1983a, 1983b) used electrooculographic methods to study smooth pursuit eye movements and attention in psychotic subjects, using an electronic pendulum which produced variations in the attentional demands of the task. Differences were found between schizophrenic and non-schizophrenic psychotics on such measures as noise/signal ratio, deviation area, microtremor rate and various of the harmonics. In the present study, tasks identical to those used in one of the earlier investigations (Andersson, 1983b) were given to a group of alcohol abusers, i.e. to persons suspected of having central nervous system disturbance due to excessive use of ethanol. Their eye tracking is compared to that of the group of psychiatric patients studied in the earlier investigation just cited, for all of whom central nervous system involvement, though conceivable, is at least not documented.

Method

Subjects

The mean age and the size of the various subject groups is presented in Table 1. Regarding the psychotic comparison groups, all the members of which had been remitted to a psychiatric hospital for short-term therapy, further details have been published elsewhere (Andersson, 1983b). All of the alcohol abusers were males, whereas 8 of the 19 psychotic patients (4 schizophrenics and 4 cycloid psychotics) were women.

Table 1. Characterization of the Subjects

Group	N	Age	
		M	SD
Schizophrenics	9	30.9	9.3
Mano-depressive psychotics	2	38.5	16.3
Cycloid psychotics	8	26.6	5.6
Alcohol abusers	20	41.2	11.3

Among the alcohol abusers (n = 20), 13 subjects (nos. 1-13) were tested twice within the four month period of data collection. In 9 of the cases tested twice, retesting occurred within 10 days (subjects 2-10); in the remaining 4 cases (subjects 1, 11-13) retesting came at the end of the data-collection period. On the first testing occasion, 17 of the 20 subjects had been receiving no medicine for at least a week, whereas two subjects (nos. 4 and 14) had been administered benzodiazepine derivates, and one subject (no. 3) had been on antihistamine for at least a week prior to testing. Seven of the 13 subjects who were tested a second time had at that point received no medicine for at least a week prior to

testing, while five subjects were on benzodiazepine derivates (nos. 4-8). In addition, at this second testing subject 6 had been administered klomeliazole, and subject 3 antihistamine.

Eleven of the subjects (nos. 2-9 and 15-17), when tested the first time, had sought out the clinic after heavy ethanol consumption lasting for about a week. Five of the other subjects (nos. 1,10,18-20) had consumed no alcohol within a period of at least two weeks, while three subjects had consumed beer or wine but no heavy alcohol for the week prior to testing. One subject (no. 11) declared he had drunk no alcohol, although a smell of ethyl alcohol was noted. When tested on the second occasion, three subjects (nos. 1,3 and 11) had sought out the clinic due to acute alcohol intoxication. Seven of the subjects (nos. 4, 9, 11, 15, 16 and 19) were characterized as showing mild alcohol abuse.

All but one of the psychotic subjects were receiving phenothiazine derivates or related substances (derivates of thioxanthene or butyrophenone); two of the cycloid psychotics and one of the manic-depressive psychotics were on lithium citrate; the latter patient and one of the cycloid psychotics were on benzodiazepine derivates; five of the cycloid psychotics and two of the schizophrenics were receiving anticholinergic drugs.

Recording Procedure

Exact details of the testing procedures are given in Andersson (1983b). An electronic pendulum, involving a "moving" light of constant speed, provided by special light diodes which could light up either red or green, was employed, the moving spot being red most of the time but becoming green for short, irregular intervals. The task involved three periods of tracking. In the first period (60 sec) the target was red. In the second period, in which there were 180 sec of tracking following a 60 sec pause, the stimulus color changed temporarily from red to green at irregular intervals, subjects being instructed to press a button each time the light changed to green; a green segment, when it occurred, comprised 1/4 of the "swing" of the pendulum in the one direction or the other. The third tracking period, 60 sec in length following a 30-sec pause, involved (as did the first) a red stimulus only.

Eye movements were registered in the AC mode with an electrooculographic technique, using a mingograph (a Beckman R-511A Dynograph Recorder). Silver-silver chloride electrodes were placed at the outer canthi for horizontal recording, and above and below the right eye for recording blinks. A ground electrode was attached to the middle of the forehead. The placement of the electrodes for horizontal recording aimed at minimizing the appearance of blinks on the recordings. Calibration was facilitated by having the subject shift his gaze several times between the two endpoints of the pendulum. The preamplifier of the mingograph drove a Tandberg (TIR) FM tape recorder operating at a 3 3/4 IPS; it was RC-coupled to balance out DC voltage, with a high pass filter (cut-off frequency 0.16 Hz) and a low-pass filter (cut-off frequency 30 Hz) for noise reduction.

Measures Obtained

The data for any given subject were processed in basic accordance with Andersson (1983b) for each of four different slightly over 30-sec segments of the total tracking task separately, each such segment comprising 12 cycles (or slightly more than this) of the pendulum. Periods 1-4 involved successive portions of the pendular task--Period 1 representing the initial segment of the first of the two red-light-only tasks, Period 2 the initial segment of the two red-and-green-light tracking tasks, Period 3 a segment of the latter task

commencing 90 seconds after the end of Period 2, and Period 4 the initial segment of the second red-light-only tracking task. Tape-recorded signals were digitized for each of the approximately 30 second segments. Data-processing involved computing eye position P from electrical voltage V at each of the sampling points through solving the differential equation $a \cdot dP/dt - b \cdot V$, where dv/dt represents change in V over time. A correction was employed for drift; this consisted in subtracting from V its mean value within each cycle. Each recording segment was shortened to exactly 12 cycles, a preliminary Fourier analysis being used in identifying cycles here. A more thoroughgoing Fourier analysis was also carried out. The following measures were obtained for each of the four periods: (1) Noise/signal ratio : the ratio between the sum of the squared amplitudes of the 2nd, 3rd, 4th, 5th and 6th harmonics, on the one hand, and the squared amplitude of the major wave (1st harmonic) on the other. For a subject following the movements of the pendulum closely, this measure would be low. (2) Deviation area : the area between the two curves describing the movements of the pendulum and of the subject's eyes, respectively. If the subject followed the pendulum closely, this measure would be low. (3) Microtremor rate : (d(tot)-d(eff))/d(eff), where d(tot) represents the total distance and d(eff) the "effective" distance the eye covered, and where d(tot) and d(eff) represent the sum of all small eye movements as measured through recording eye position at 3.66 msec intervals, and at intervals nine times larger (33 msec), respectively. For each such measure, a summary measure of the subject's overall tracking performance (OTP) during the four periods together was calculated. In addition two types of difference score, Dif-1 and Dif-2, were obtained for each of the measures (1) to (3) above, in accordance with Andersson (1983a). Dif-1, the difference (1+4)-(2+3), where the numbers here refer to the successive periods, indicates the effect on eye trackling performance of changing from the less attention-demanding conditions (red-light-only) to the more demanding (changing light color). Dif-2, the difference (1+2)-(3+4), represents the effect of practice. Using these summary measures, comparisons were made between the alcohol abuser and the psychotic groups, the latter group comprising all three groups of psychotic patients mentioned above. Comparisons were made between occasions A (first testing) and B (retest) for all the above measures.

Results

Inspecting the mingographic recordings for irregularities, the most striking characteristic among the majority of alcohol abusers was the frequent presence of macro squarewave jerks in the same direction as that of the target, a macro squarewave jerk being defined here as a complex comprising an initial saccadic deviation of at least 10^{o} amplitude from actual tracking, followed after normal reaction time (about 200 msec) by a catch-up saccade in the direction opposite to that of the initial saccade. Such deviations as counted from computer graphs of foveal position vis à vis the target (see Figure 1 for an example), were found to a significantly more frequent extent in alcohol abusers than in psychiatric patients, occurring at least four times in total during the 30-sec periods of tracking in 8 of the 20 alcohol abusers but in only 2 of the 19 psychiatric patients ($p=0.039$, Fisher test), corresponding figures in occasion b being 5 of 13 and 1 of 15, respectively ($p=0.023$, Fisher test). A typical saccadic performance, on the other hand, was evident in subject 1 when tested approximately 24 after having finished a one week-period of heavy ethanol consumption (Figure 2).

On occasion A, the seven mild abusers were found to have very few macro squarewave jerks (less than 4 in total), whereas eight of the heavier abusers ($n=13$) demonstrated macro squarewave jerks to a significantly higher

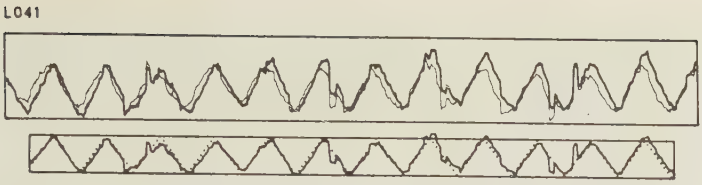

Figure 1. Eye tracking pattern in an alcohol abuser (no.6) during occasion 1 (Period 1) with macro squarewave jerks appearing, all in the same direction as the target. Movement to the right = upwards, to the left = downwards. The lower, more abbreviated record has been corrected for drift and shortened to 12 cycles. Thin curve = initially registered voltage; thick curve = foveal position; dotted, saw tooth curve = stimulus (light) position.

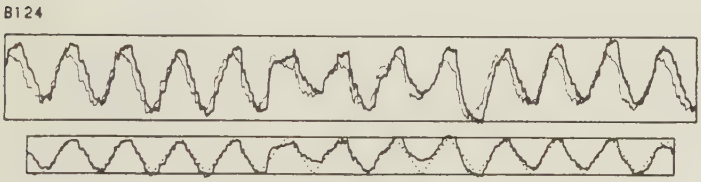

Figure 2. Saccadic eye movements in a alcoholic abuser (no. 1) with heavy alcohol comsumption during the week prior to testing.

extent (range 4 - 15 in total each; p=.010, Fisher test). No such relation was evident when comparing subjects who had consumed alcohol during an extended period prior to testing on occasion A (nos. 2-9 and 15-17) and those who had no such recent history of drinking (in the former group, 5 showing values greater than 4, and 6 smaller than or equal to 4, the corresponding figures for the latter group being 2 and 6, respectively).

In a descriptive sense it could be noted that two of the mild alcohol abusers (subjects 8 and 16) who on occasion A had shown no occurrence of macro squarewave jerks (no. 8) or only one occurrence (no. 16), demonstrated such deviations to a greater extent on occasion B, about one week later (showing in total 9 and 18 such deviations, respectively). At the same time, subject 3 showed 12 macro squarewave jerks in total on occasion A, when not having consumed alcohol for some time, but no such deviation at all (the total pattern being saccadic) when tested on occasion B about one week later, after a period of heavy drinking.

OTP-scores: No significant differences between the psychotic patients and the alcohol abusers were found regarding either noise/signal ratio or deviation area as measured on occasions A and B. Both groups showed relatively high values at

first testing as compared with the small sample of normals (n=4) tested once in Andersson (1983a), two of the normals showing the lowest noise-signal ratio of all the subjects. As to occasion A, four of the seven alcohol abusers who had only mild alcohol abuse were found within the range of normals, both as regards noise/signal ratio and deviation area, the four subjects involved being the same in both cases (nos. 19, 14, 16 and 9).

The most striking result was that concerning microtremor rate. Here the difference between the alcohol abusers and psychotic patients was categorical, all the alcohol abusers scoring lower than any of the psychotic patients, whereas the normals all showed values rather similar to those of the alcohol abusers (range being 3.067 - 5.752 for normals, who were tested on occasion A only, its being 2.013 - 5.610 on occasion A and 0.737 - 2.999 on occasion B for the alcohol abusers, and 9.081 - 23.478 on occasion A and 14.749 - 24.284 on occasion B for the psychotic patients).

Dif-1 and Dif-2 scores: For noise/signal ratio performance was found to be better generally under the more than under the less attention-demanding conditions (i.e, Dif-1 scores were predominantly positive), both for occasion A (13+, 7-, n.s., chi^2 here, as in the following) and occasion B (9+, 3-, n.s.). Andersson (1983b) found a similar tendency among psychotic patients, both for occasion A (15+, 4-, $p<.02$) and occasion B (12+, 3-, $p<.05$). The results for the alcohol abusers appeared reliable, only 2 of 12 subjects (nos. 5 and 13) showing a different sign (+ or -) on occasion B than A (one subject, in addition, changing from + to no difference), quite in line with what was found in the psychotic group, where corresponding figures were 2 of 15 patients. As to Dif-2 scores on occasion A, alcohol abusers showed a decrease in noise/signal ratio over time (15 decreasing, 5 increasing, $p<.05$), while in psychotic patients a certain tendency to the contrary was found (7 decreasing, 12 increasing, n.s.). A tendency to perform better on this measure under the more than under the less attention demanding conditions, as well as over time during a testing occasion, was evident also among the 11 patients who, when tested the first time, had sought out the clinic after consuming ethanol heavily for about a week prior to testing. Comparing occasions A and B, changes occurred in 8 of 13 cases, seven subjects changing from + to - (nos. 2, 5, 7, 9, 10, 12 and 18) and one only (no. 13) from - to +.

Concerning deviation area, there was no indication, such as had been observed in psychotic patients (Andersson 1983a, 1983b), that performance was better under the more than under the less attention-demanding conditions (dif-1 scores on occasion A: 10+, 10-, n.s.; on occasion B: 5+, 8-, n.s.). Comparing occasions A and B, only 5 of 13 patients showed the same type of tendency on both occasions (3++, 2--), whereas 13 of the 15 psychotic patients in Andersson (1983b) demonstrated high retest reliability (7++, 6--).

In alcohol abusers, microtremor rate tended to be higher under the more than under the less attention demanding conditions (Dif-1) on occasion A (14+, 6-, n.s.), whereas, on occasion B, the number of increases and decreases was equal (7+, 7-, n.s.). As to Dif-2 scores, there was a tendency for microtremor rate to decrease over time, both on occasion A (12-, 8+, n.s.) and occasion B (8-, 6+, n.s.). Likewise, on occasion A, the above mentioned group of eleven subjects with heavy ethanol consumption just prior to their first testing showed a tendency, although not significant, in the same direction as that of the total abuser group. Andersson (1983b) found microtremor rate in psychotic patients as measured by Dif-1 scores to also be predominantly positive (17+, 2-, $p<.001$) on

occasion A, whereas on occasion B results were not significant (9+, 6-). As to Dif-2 scores in the psychotic patients, a decrease over time was found, both on occasion A (14-, 5+, $p<.05$) and occasion B (12-, 3+, $p<.05$).

Discussion

Views differ regarding the phenomenon of macro squarewave jerks. Couch and Fox (1934), studying 117 patients with various mental diseases, reported lapses of attention in 60 of the patients, who otherwise displayed what was interpreted as normal ocular response. In pendular pursuit such evidence of inattention included deviations ahead of the stimulus, followed after a brief period by refixation to the predetermined position of the stimulus. However, these authors explicitly observed lapses of attention to be extremely rare in records from normal subjects.

Jung and Kornhuber (1964), investigating tracking movements of the eyes to a horizontal pendulum in patients with various neurological syndromes, also indicated normal subjects to in some cases demonstrate interruptions of an otherwise sinusoidal curve by quick intermittent fixations of other objects, although no information is given as to number of normals studied.

Examining patients with otoneurological disorders in response to a pendular stimulus, Benitez (op. cit.) considered as normal even recordings of patterns which were characterized by a few intermittent non-nystagmic movements superimposed on a sinusoidal curve. Although it is at least unclear whether a sample of otoneurological patients can be considered as representative of normals, this view seems to have pervaded later investigations (e.g., Holzman, Proctor, Levy, Yasillo, Meltzer and Hurt, 1974; Lipton, Frost and Holzman, 1980). The result reported in the present investigation, showing psychotic patients to have significantly less macro squarewave jerks than alcohol abusers and also indicating the heavier alcohol abusers to demonstrate these phenomena to a greater extent than mild alcohol abusers, may instead suggest pathological involvement to lie at the basis for this phenomenon (cf. Dell'Osso, Troost and Daroff, 1975). As is evident from inspection of the graphs showing target position vis a vis foveal position (see Figure 1 for an example), there is no evidence for nystagmic involvement here, the initial (abnormal) saccades of the macro-square complexes not being correlated with delayed foveal targeting. Rather, they may perhaps be interpreted in terms of a saccadic pulse generator being triggered by an unwanted supranuclear command signal (cf. Zee and Robinson, 1978).

Although it was not possible to distinguish psychiatric patients from alcohol abusers on the basis of the overall measures of noise/signal ratio or deviation area, there is another phenomenon which merits special interest, namely that of microtremor being categorically higher in psychotic patients than in alcohol abusers. Although no differences were observed between psychotic patients and alcohol abusers in patterns of response over time during a testing session or as cognitive strain increased, these aspects of the tracking task did not seem to account for the very large differences found on this measure, leaving the possibility open that disturbance of a central nature is present in the psychotic patients.

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EYE TRACKING PERFORMANCE AND ATTENTION IN ALCOHOL ABUSERS, PSYCHOTIC PATIENTS AND NORMALS - TOWARDS A MULTIDIMENSIONAL MODEL

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Pendular eye tracking performance of alcohol abusers (n=3), psychotics (n=4) and normals (n=7) was studied, using electrooculography, the alcohol abusers being tested 3, 9 and 10 times, respectively, over an extended period. An electronic pendulum involving a "moving" light of constant speed was employed, there being two tasks, one less and the other more attention-demanding (red light only vs. having to press a button each time the light changed to green). Noise/signal ratio, deviation area and microtremor rate were calculated. Results indicate psychotic patients to be high on both noise/signal ratio and deviation area compared with normals. Alcohol abusers appeared to be low in microtremor rate when in a sober condition but to show a marked increase in microtremor rate to a level well above that of normals and psychotics when under the influence of alcohol. In the alcohol abuser group, an increase in cognitive strain was found to produce an improvement in performance in terms of noise/signal ratio and a decrement in performance in terms of deviation area. This apparent discrepancy was interpreted as indicating cognitive strain to increase deviations from correct following at a level intermediate between the coarser deviations measured by noise/signal ratio and the finer ones measured by microtremor. Evidence from one of the normals tested when in a highly stressed state, who showed a drastic increase in microtremor rate over time, suggested effects of stress on microtremor. Analyzing separately the results of each subject's most recent testing, a special computer program developed so as to more systematically study the various types of deviation from smooth eye tracking was employed. From the eye position curve the program computed sliding means over 16- and 128-point intervals, respectively, so as to produce two smoothed curves interpreted as being fine and coarse representations of subjective stimulus. Registering deviations of the recordings upwards or downwards from these two curves allowed a detailed analysis of differences between the subject groups in their manner of following the stimulus position. Cluster analysis of the results succeeded quite well in distinguishing on the three-cluster level between three groups, representing the two alcohol abusers who were acutely intoxicated, the four psychotics, and the seven normals together with an alcohol abuser who had been sober for some time. At the five-cluster level the latter subject and one of the normals formed a cluster. Analysis of the results for the various measures, considered separately, also suggested marked differences in eye tracking between the subject groups.

Introduction

Several studies have shown eye tracking impairments to be more characteristic of schizophrenics than of other diagnostic groups (for a review see Lipton et al. 1983). However, impairments similar to those found in schizophrenia have been

reported to occur in other diseases, as well as in certain drug-induced states (e.g., Corvera et al. 1973, Drischel 1968, Flom et al. 1976, Holzman et al. 1975, Levy et al. 1981). In eye tracking studies involving 19 psychotic patients (predominantly schizophrenics and cycloid psychotics, Andersson 1983b) and 20 alcohol abusers (Andersson 1984), the present author found none of the overall macro-level noise/signal ratio and deviation area measures employed to distinguish between the two groups. Both types of measures were responsive to situational changes, however, performance being found to be better under more than under less attention-demanding conditions, a result obtained for both groups in terms of noise/signal ratio, but for the alcohol abuser and not the psychotic patient group in terms of deviation area. Macro squarewave jerks were found to be more frequent in alcohol abusers than in psychiatric patients. Regarding microtremor level, Andersson 1983a found hebephrenics to have a significantly higher microtremor rate than non-hebephrenic schizophrenics and cycloid psychotics, a small reference group of normals (n=4) falling within the range of the latter two groups. In a more recent investigation, Andersson 1984 found microtremor rate to be categorically higher in psychotic patients generally than in alcohol abusers. The results just cited call for further study in order to clarify the apparent relationships involved and explore various questions they raise.

STUDY I

Test-retest data reported in Andersson (1983b and 1984) suggested certain eye tracking dysfunctions at the microlevel to be characteristic of psychotics generally. Nevertheless, the question of the stability over time of the microtremor rate results obtained, remains. To explore this question, particularly in the alcohol abuser group, two of the 20 alcohol abusers studied earlier and reported on in Andersson (1984) were followed for a period of approximately a month, one of the subjects being tested nine times and the other ten times during this period. In addition, about three months later these same two subjects were tested again together with a third person, who was also from the group of alcohol abusers tested originally. Results from these three subjects were compared with those of four psychotic outpatients (three of whom were diagnosed as schizophrenics) and of seven normal subjects. Microtremor rate was of primary interest, although measures of noise/signal ratio and deviation area were also obtained for each of the subjects.

Method

Recording Procedure Details of the testing procedures are given in Andersson (1983b). Eye movements were registered in the AC mode, using a mingograph. Silver-silver chloride electrodes were placed at the outer canthi for horizontal recording and above and below the right eye for recording blinks. A ground electrode was attached to the middle of the forehead. Placement of electrodes for horizontal recording aimed at controlling blinks in the recordings. Calibration was facilitated by having subjects shift their gaze several times between the two endpoints of the pendulum. The mingographic preamplifier drove a Tandberg FM tape recorder; it was RC-coupled to balance out DC voltage, with a high pass and low pass filter (cut-off frequencies 0.16 and 30 Hz, respectively) for noise reduction.

The electronic pendulum involved a "moving" light of constant speed, provided by special light diodes which lit up either red or green. The tracking task consisted of three parts. In the first part (60 sec) the target light was red. In the second part, involving 180 secs of tracking following a 60 sec pause, the light changed temporarily to green at short irregular intervals. Subjects were to press a button

each time the light changed to green; a green segment, when occurring, comprised a one quarter "swing" of the pendulum in the one direction or the other. The third tracking part, 60 sec in length following a 30-sec pause, involved a red stimulus only.

Measures Obtained Data processing for any given subject followed Andersson (1983b, 1984) and was carried out for each of the four slightly over 30-sec segments of the total tracking task separately, such a segment comprising slightly more than 12 pendular cycles. Period 1 represented the initial segment of the first red-light only tasks, Period 2 the initial segment of the two red-and-green tasks, Period 3 a segment of the latter task commencing 90 seconds after the end of Period 2, and Period 4 the initial segment of the second red-light only tracking task. Tape-recorded signals were digitized at a rate of 8,192 sampling points for each segment. Data-processing involved computing eye position from electrical voltage at each of the sampling points; a correction was employed for drift, consisting of subtracting from the electrical voltage its mean value within each cycle. Each recording segment was shortened to exactly 12 cycles, a preliminary Fourier analysis being used in identifying cycles.

The following measures were obtained for each of the four periods: (1) Noise/signal ratio: the ratio between the sum of the squared amplitudes of the 2nd to 6th harmonics, and the squared amplitude of the major wave (1st harmonic). A low value, as regards this measure, indicates the subject to be following the pendulum closely. (2) Deviation area: the area between the two curves, describing the movements of the pendulum and of the subject´s eyes, respectively. A low value here too indicates the subject to be following the pendulum closely. (3) Microtremor rate: (d(tot)-d(eff))/d(eff), where d(tot) represents the total distance and d(eff) the "effective" distance the eye covered, d(tot) and d(eff) representing the sum of all small eye movements as measured by recording eye position at 3.66 msec intervals, and at intervals nine times larger (33 msec), respectively.

For each measure above, a summary measure of subject´s overall tracking performance (OTP) was calculated, as were two difference scores. Dif-1, which is the difference (1+4)-(2+3), where the numbers refer to the successive periods, indicates the effect of changing from the less attention-demanding conditions (red-light only) to the more demanding (changing light color). Dif-2, which is the difference (1+2)-(3+4), represents the effect of practice.

Subjects Of the alcohol abusers reported on in Andersson (1984), two subjects, designated (just as they were in Andersson 1984) as subjects 5 and 6 (aged 34 and 32 years, respectively), were selected randomly from the group of alcohol abusers available in the clinic at the time and were asked to appear in the clinic at least twice each week for continued testing. Prior to this arrangement, both subjects had been tested twice (Andersson, op. cit.), subject 5 being re-tested on the first and subject 6 on the second day after the initial testing; both subjects had imbibed heavily prior to the initial testing but had not consumed alcohol since then. The extended period of testing embraced one month for subject 5, and 16 days for subject 6, the former subject being tested seven times and the latter eight times during that period. For both subjects, the extended period of testing became terminated through their relapse into a new period of abuse. Subject 6 was tested once at the end of this period of heavy alcohol abuse, during which he reported having drunk at least 75 cl 40% ethanol daily. Subject 5, who had been administered a single dose of benzodiazepine derivates on the second testing occasion, received no medicine until four days prior to the ninth testing, when another dose of benzodiazepine derivates was administered. Subject 6 who had

been without medicine during at least a week prior to the first testing, was administered klomeliazole and benzodiazepine derivates two days prior to the second testing and was still on benzodiazepine derivates when tested the third time; prior to the fourth testing, he had been without the drug for three days, no medication being given him then until just prior to the tenth testing, when he was put back on benzodiazepine derivates .

After an extended period without testing, some 3 months after testing had commenced, subjects 5 and 6 were tested once more. At this time, subject 6 declared he had drunk no alcohol for a week, whereas subject 5 reported having drunk at least 20 cl of 40% ethanol just a few hours before testing. The latter was accompanied by subject 3 (age 43 years), who had been tested twice before; though cooperative, this subject was even more acutely intoxicated by ethanol than subject 5, declaring he had drunk about 35 cl of 40% ethanol just one hour before. None of the three subjects were on additional drugs at this testing occasion.

Of the four psychiatric out-care patients (referred to here as subjects 21-24) subject 21 (male, age 32 years) was diagnosed as a schizophrenic of the simplex type, subject 22 (female, age 42.6 years) as a psychotic of the undifferentiated type, subject 23 (male, age 55.3 years) as a schizophrenic of the undifferentiated type, and subject 24 (female, age 28.8 years) as a schizophrenic of the hebephrenic type. Subjects 21, 23 and 24 were on phenothiazine-derivates, whereas subject 22 was on a tricyclic antidepressive. In addition, subject 21 was receiving an anticholinergic.

As to the seven normals (subjects 25-31, mean age = 37.6 years, s.d. = 6.9), all were recruited among the personnel of the health care center at which the investigation was carried out. Six of these subjects were male and one (subject 29) was female. None of them reported use of drugs at the time of testing. One of the normals, subject 31, appeared at the laboratory in a very stressed condition, due to having to get to another appointment afterwards. As time passed he appeared increasingly worried about being late, although the experiment was not interrupted.

Results

OTP-scores: Table 1 shows results for overall tracking performance on each testing occasion for the three alcohol abusers (subject 3, 5 and 6 tested three, nine and ten times, respectively), the four psychotic patients (tested once) and the seven normals (tested once).

Each of the psychotic patients and one of the alcohol abusers (subject 5) scored higher on noise/signal ratio than did any of the normals, the superiority of this latter subject compared to each of the normals being found on each of the ten testing occasions. The latter subject's scores on this variable were at their lowest level when the subject was directly under the influence of ethanol (testing 5:10). A similar tendency was evident in subject 3, who only scored within the range of the normals when highly intoxicated (testing 3:3), scoring higher than all of the normals on the other two testings.

Deviation area was found to be higher in all four psychotic patients than in any of the seven normals, whereas in alcohol abusers that measure showed considerable fluctuations. Those two alcohol abusers who were tested repeatedly over an extended period of time and were partially on benzodiazepine medication (subjects 5 and 6) were found in intraindividual comparisons to show consistently lower

TABLE 1

OTP-scores, Dif-1- and Dif-2-values
of alcohol abusers, psychotic patients and normals

No. of subject and testing	Noise/signal ratio			Deviation area			Microtremor rate		
	OTP-score	Dif-1-score	Dif-2-score	OTP-score	Dif-1-score	Dif-2-score	OTP-score	Dif-1-score	Dif-2-score
ALCOHOL ABUSERS									
3:1	.523	+.243	-.117	1.379	+.213	-.317	5.030	-.182	+.152
:2	.448	+.112	-.026	1.684	+.392	+.164	3.837	-.183	+.085
:3	.363	-.047	-.039	2.600	-.344	+.062	9.806	-.554	+.772
5:1	.664	+.270	+.046	1.460	+.486	-.140	2.013	-.277	+.129
:2	1.057	-.091	-.185	1.354	-.272	-.078	2.855	+.043	-.053
:3	.730	+.218	-.174	1.971	+.253	-.525	2.258	-.272	+.176
:4	.604	+.224	-.062	2.169	-.019	-.257	7.753	-.737	-.681
:5	.804	-.064	+.110	1.874	-.178	+.146	1.742	+.020	-.004
:6	.652	+.170	-.026	1.874	-.054	-.360	5.063	+.059	-.020
:7	.674	+.050	-.042	1.749	-.273	-.295	3.858	+.024	+.024
:8	.531	+.095	-.011	1.642	-.262	-.044	2.632	-.134	-.036
:9	.547	+.071	+.125	1.405	-.021	+.052	2.994	-.118	-.118
:10	.522	+.072	-.050	1.699	-.027	-.079	10.637	-.259	-.197
6:1	.437	+.081	+.001	1.392	+.290	-.014	2.533	+.003	-.075
:2	.329	+.017	-.029	.910	-.058	+.196	2.974	-.068	+.094
:3	.328	+.094	-.038	.942	-.010	-.236	2.218	-.086	+.128
:4	.485	+.069	-.095	.935	-.049	-.099	2.122	-.014	+.204
:5	.366	-.008	-.008	.806	-.082	-.082	2.945	+.089	+.361
:6	.408	+.050	-.006	.954	-.090	-.068	2.984	-.003	-.122
:7	.580	+.002	+.052	1.210	-.062	-.078	3.046	+.094	+.244
:8	.385	+.017	+.003	.761	-.083	-.069	3.577	-.110	+.159
:9	.430	+.014	-.016	.897	-.089	+.079	4.937	+.109	+.317
:10	.408	-.008	-.012	1.052	+.028	-.032	2.936	-.100	-.214
:11	.388	+.024	-.022	1.460	+.104	+.196	4.884	+.022	+.302
PSYCHOTIC PATIENTS									
21:1	.485	+.177	-.061	1.661	+.631	-.419	8.483	-.465	+1.051
22:1	.457	-.021	-.061	1.840	-.504	-.142	7.765	-.877	-.149
23:1	.466	-.036	+.040	2.459	+.167	+.781	6.466	+.598	+.862
24:1	.418	+.066	+.026	1.854	+.391	-.013	5.812	-.010	-.012
NORMALS									
25:1	.330	+.032	±.000	1.169	+.055	-.205	7.865	+.039	+.109
26:1	.382	+.012	+.012	1.073	+.155	+.109	6.916	-.006	+.098
27:1	.319	+.029	+.007	1.277	-.017	+.081	6.521	+.013	+.303
28:1	.416	+.018	+.010	1.168	-.102	-.272	6.171	+.155	+.065
29:1	.294	+.022	-.008	1.461	-.305	-.063	7.363	-.087	+.257
30:1	.311	-.017	-.033	1.189	+.029	-.031	7.259	-.409	+.515
31:1	.274	+.037	+.015	1.266	+.036	-.184	8.416	-.176	-1.246

deviation area scores while on the medication.

No differences were found between psychotic patients and normals on OTP-measures of microtremor rate. Microtremor rate in alcohol abusers showed considerable fluctuations over testing occasions but was generally relatively low except under conditions of acute intoxication, also being low when the subjects were on benzodiazepine derivates (subjects 5 and 6 at testings 5:2, 5:9, 6:2 and 6:3). In alcohol abusers who were acutely intoxicated (subjects 3 and 10, testings 3:3 and 5:10, respectively), however, microtremor rate increased to levels well above those registered in psychotic patients and normals. When tested about a day after a drinking period had ended, subjects 5 and 6 alike scored comparatively low on this measure (testings 5:1, 6:1 and 6:10). A similarly low microtremor rate was also found in those alcohol abusers for whom there was no sign of their having consumed alcohol for several days or weeks.

Dif-1 and Dif-2 scores relating to noise/signal ratio. Noise/signal ratio performance of the alcohol abusers was better generally under the more than under the less attention-demanding conditions, as shown by the Dif-1 scores being predominantly positive. Similar results were also found for six of the seven normals, although their improvement under the more attention-demanding conditions was only slight. Of the four psychiatric patients, two showed marked improvement and two a slight decrease in performance under the more attention-demanding conditions. As to Dif-2, the three alcohol abusers showed performance impairment over time, 18 out of their 24 scores being negative, whereas for the normals and the psychotic patients no clear tendencies of this sort were found.

Dif-1 and Dif-2 scores relating to deviation area. No clear tendencies regarding Dif-1 scores were found for the normal and psychotic groups. In 17 of the 24 records of the alcohol abusers Dif-1 scores indicated performance in terms of deviation area to deteriorate under the more attention demanding condition. A tendency for performance to deteriorate over time (Dif-2 scores) was noted in the alcohol abusers, and such a tendency was also noted in 5 of the 7 normals and in 3 of the 4 psychotic patients.

Dif-2 scores relating to microtremor rate were found in the normal group to be predominantly positive (6+, 1-), indicating a decrease in microtremor rate over time. Subject 31, who appeared at the laboratory in a highly stressed state, was the only normal subject who increased his microtremor rate over time, his increase being quite drastic.

Discussion

Psychotic patients appear to be high on both noise/signal ratio and deviation area compared with normals, but do not differ from normals as regards microtremor rate. Alcohol abusers in turn appear to show low microtremor rate when in a sober condition but to show a marked increase in microtremor rate to approxiomately the level of normals and psychotics when under the influence of alcohol. Thus, different mechanisms appear to be involved in the eye-tracking deficiencies of psychotics and alcohol abusers. One can speculate that for alcohol abusers the rise in microtremor rate to about the level of normals, which the use of large quantities of alcohol has as an immediate effect, may serve some functional end. It would be of interest to know whether their low microtremor rate when not intoxicated is produced by their long-term alcohol abuse or is inherited.

All of the three types of measures just considered--noise/signal ratio, deviation

area and microtremor rate--appear sensitive to the effects of an increase in cognitive strain and of fatigue, as shown by the respective Dif-1 and Dif-2 measures. In both the normal and alcohol abuser groups an increase in cognitive strain was found to yield an improvement in performance as far as the noise/signal ratio measure was concerned. In the case of deviation area measure the result for the alcohol abusers appeared to be just the opposite, performance showing a decrement under conditions of increased cognitive strain. The apparent discrepancy here can be interpreted as a difference in the type of performance decrements involved, where the decrements are of a more coarse nature in the case of noise/signal ratio, which takes account of the first six harmonics only, whereas deviation area can be said to include decrements of a greater number of types. In alcoholics, therefore, an increase in cognitive strain, although producing a decrease in coarser deviations from correct pursuit, appears to yield an increase in total deviations. The latter effect can be assumed to be based on an increase in deviations at an intermediate level between that of the first six harmonics and of microtremor.

The finding that for normals the improvement in performance shown on the noise/signal ratio measure under the more attention demanding conditions was only slight compared to that in the alcohol abusers, can be seen as based on the fact that for the normal subjects, who already tracked quite well under the less attention demanding conditions, there was less room for improvement. The result that the normal subject who was highly stressed showed the highest microtremor rate of any of the normals and that his microtremor rate increased dramatically over time, despite his noise/signal ratio scores indicating his tracking at the macrolevel to be the best among the normal subjects who were tested, suggested that stress tends to strongly affect specifically microtremor. The subject in question appeared to have achieved high performance at one level (macro-level) at the cost of increased activity at the microtremor level.

STUDY II

This study emanated from the need of a more extensive and multidimensional analysis of eye tracking records identifying the occurrence of various types of deviations.

Method

To this end, a program for a detailed analysis of various deviations from smooth eye tracking was developed, partly on the basis of a reanalysis of the records of four subjects reported on earlier (see Andersson 1983b, Figures 1-2; Andersson 1984, Figures 1-2), subjects considered illustative of eye tracking in psychotic patients and alcohol abusers, respectively. This program was then used to analyze again data from the most recent testing made of each of the 14 subjects reported on in Study I, the data for each subject being the same as that analyzed for the respective testing session in Study I and comprising, as there, four periods of about 30 sec each. The fact that the records of the analog signals had all been saved on a single tape and that the analog-to-digital conversion was performed on a single day can be seen as having tended to keep chance variations due to the equipment at a minimum. For each period of tracking analyzed, which comprised 12 waves each with an amplitude of approximately +/-21 degrees, smoothing was carried out with the aim of obtaining a representation of subjective stimulus

position. An initial smoothing was accomplished by computing sliding means over 16-point intervals, one intervel corresponding to 10 msec (16 intervals thus corresponding to 0.16 sec). The resulting curve will be referred to as the V4 curve; it closely resembles the eye position curve, but excludes certain apparently unconscious tremor, which will be referred to here as macrotremor to distinguish it from the microtremor described above.

A second smoothing involved quadratic interpolation over 128-point intervals, corresponding roughly to half a wave length, i.e. the distance from a wave crest to the following trough. This curve will be referred to as the V7 curve. Being close in form to the curve representing the movements of the target, this curve indicates readily the extent to which the gross following movements remained on target.

The two types of sliding curves, based respectively on 16-point and 128-point intervals, were seen as fine and coarse representations of the subjective stimulus position.

Macrotremor was computed by identifying and counting both the upwards and downwards deviations of the eye position curve from the V4 curve and then identifying bands of adjacent deviations. This analysis aimed at finding bands of deviations of roughly equal size; single large saccades were excluded automatically through a rule by which any deviation, the neighbors of which were less than half as large, being eliminated. For each tracking period the following computations were obtained: a) the number of macrotremor deviations, b) their mean size, c) their width, d) their speed and e) the percentage of the V4 curve involved.

The analysis of jerks took into account deviations of the V4 curve from the V7 curve. Deviations to either side which were sufficiently long and steep were classified as jerks. The criterion for steepness here was that the jerk be at least double the speed of the stimulus, the criterion for size being (somewhat arbitrarily) set to 3.15 degrees (corresponding to 0.15 of the maximal amplitude in Figure 1). Deviations larger than 2.1 degrees (corresponding to 0.1 unit in Figure 1) were analyzed in more detail. A deviation that began and ended with a jerk was classified as a macro squarewave if the line between the jerks was flat, horizontal, and of minimum temporal size. Flatness was defined as existing if the V4 curve deviated from the center point of a straight line between the jerks by less than 14% of the center point´s distance from the V7 curve. Horizontalness was defined as existing if the slope of the line was less than half the speed of the stimulus. Deviations bounded by two jerks but not fulfilling all the other criteria, as well as deviations bounded by a jerk on one side only but fulfilling the criteria above, were thus identified. In summary, the following computations of the V4 curve from the V7 curve were performed for each of the four periods of tracking: f) number of deviations of the V4 curve from the V7 curve, g) mean size of these deviations, h) number of deviations greater than 2.1 degrees as defined above, i) mean size of the greater deviations, j) number of jerks, k) mean size of jerks, l) mean slope of jerks, m) mean number of recoils, n) percentage of the V7 curve involved by recoils, o) number of plateaus and p) mean number of macro squarewaves.

OTP, Dif-1 and Dif-2 scores were obtained for each of the measures a) through p) above for any given subject, the rules followed being in accordance with those given in Study I. Separate cluster analyses employing Ward´s (1963) minimum variance method were performed for the OTP measures and for the combined OTP, Dif-1 and Dif-2 measures, not only regarding deviations of the eye position curve from the V4 curve, (i.e., regarding macrotremor) and of the V4 curve from

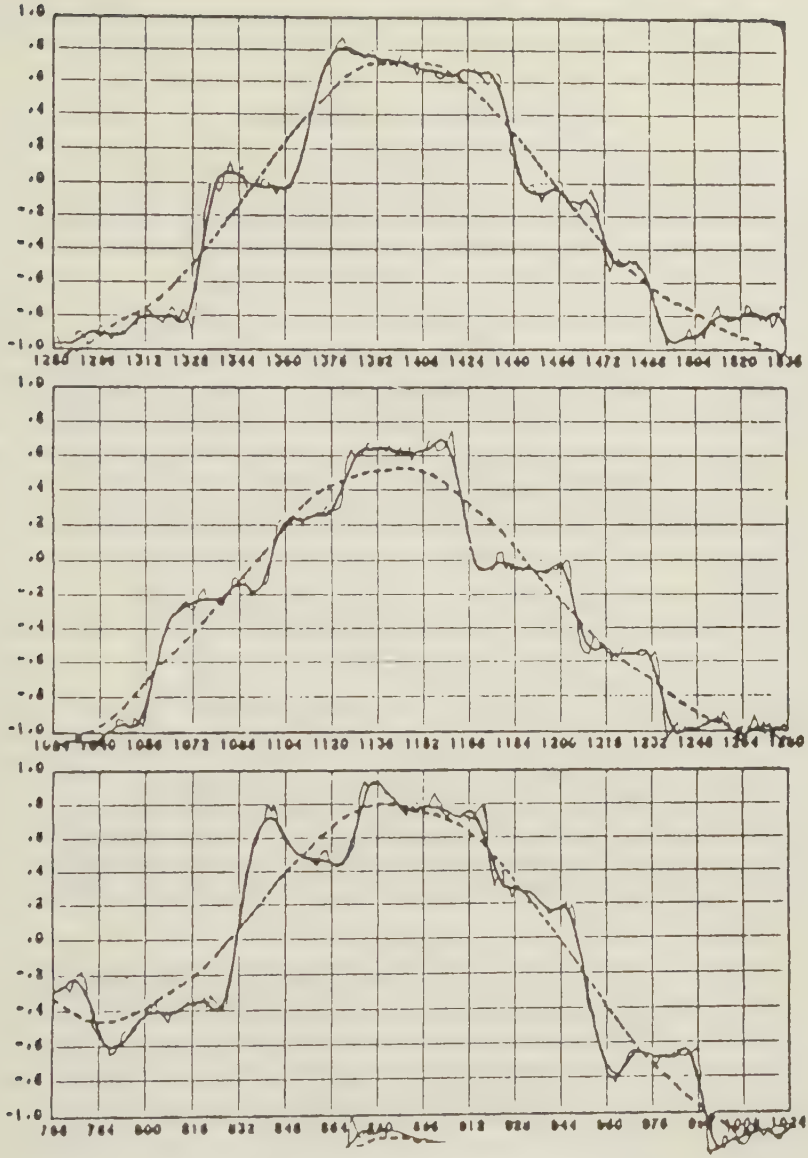

Figure 1. Eye-tracking segments (2.5 sec each) from the record of an acute alcohol abuser (no.03). The lighter line represents eye position, the darker line the V4-curve, and the dotted line the V7-curve.

the V7 curve (i.e. regarding V7-deviations), but also regarding OTP-measures for macrotremor and V7-deviations combined, and regarding the combined OTP, Dif-1 and Dif-2 measures for macrotremor and V7-deviations combined--resulting in six cluster analyses.

Results and Interpretation

Figure 1 presents eye-position, V4- and V7-curves obtained for three pendular cycles from the recording of one of the acutely intoxicated subjects (no. 3:3). Tracking here shows a typical step-wise pattern, although this does not prevent the V7 curve from appearing to follow the rhytmic oscillations of the target fairly closely.

Results of the cluster analyses are presented in Figure 2. Cluster analysis (6), which is based on all OTP, Dif-1 and Dif-2 scores obtained from computations (a) through (o) and thus involves all macrotremor and V7-deviation measures combined, succeeds quite well in distinguishing on the three-cluster level between the two acute alcohol abusers, the four psychotics and the seven normals, the sober alcohol abuser being found in the same cluster as the normals. Cluster analyses (1) and (2), based on macrotremor OTP-scores, processed separately and in conjunction with macrotremor Dif-1 and Dif-2 scores, respectively, differentiate on the two branch level between the acute alcohol abusers and the remaining subjects, though no very clear cleavage between subgroups is evident among the remaining subjects.

Cluster analysis (3), based on the V7-deviation OTP scores, shows a clear cleavage at the first branching, between the four psychotics and the two acute alcohol abusers, on the one hand, and the remaining group consisting of all the normals and the sober alcohol abuser on the other. On the five-cluster level here, one of the acute alcohol abusers, subject 05, is joined by subject 23 from the psychotic group, while subject 03, the other acute alcohol abuser, forms a cluster of his own. In cluster analysis (4), which involves, in addition to the V7-deviation OTP-scores, the V7-deviation Dif-1 and Dif-2 measures, separation of the psychotics from the acute alcohol abusers is more obvious. On the four cluster level here, one cluster is occupied by the psychotic subject 23 and a second by the remaining three psychotics, with the two alcohol abusers forming a cluster of their own, and all the normals and the sober alcohol abuser being included in the remaining cluster.

Cluster analysis (5), based on all the OTP-macrotremor and V7-deviation measures, results, at the three cluster level, in a clear separation between the chronic alcohol abusers, the four psychotics and the remaining subjects, the latter cluster embracing all the seven normals and the sober alcohol abuser. In cluster analysis (6), where Dif-1 and Dif-2 scores have been added to the variables just mentioned so that all measures of macrotremor and V7-deviation area are included, a similar cleavage is found, and in addition, at the five-cluster level, the sober alcohol abuser appears in a separate cluster together only one of the normals (subject 27).

On the OTP-scores for macrotremor, the number of deviations (measure (a)) was categorically lower in the two acute alcohol abusers than in any of the other subjects, the mean of the number of deviations per period being 346 and 459 respectively for the acute alcohol abusers 3 and 5, in contrast the mean number of deviations per period for the remaining subjects as a group being 621 (s.d.=37.3). Also, the two acute alcohol abusers were shown to be the lowest of all the subjects on mean size (b), mean velocity (d) and percentage of the V4 curve involved (e). In addition, mean width of deviation (c) was rather low in the acute alcohol abusers as compared with the other subjects. No categorical differences

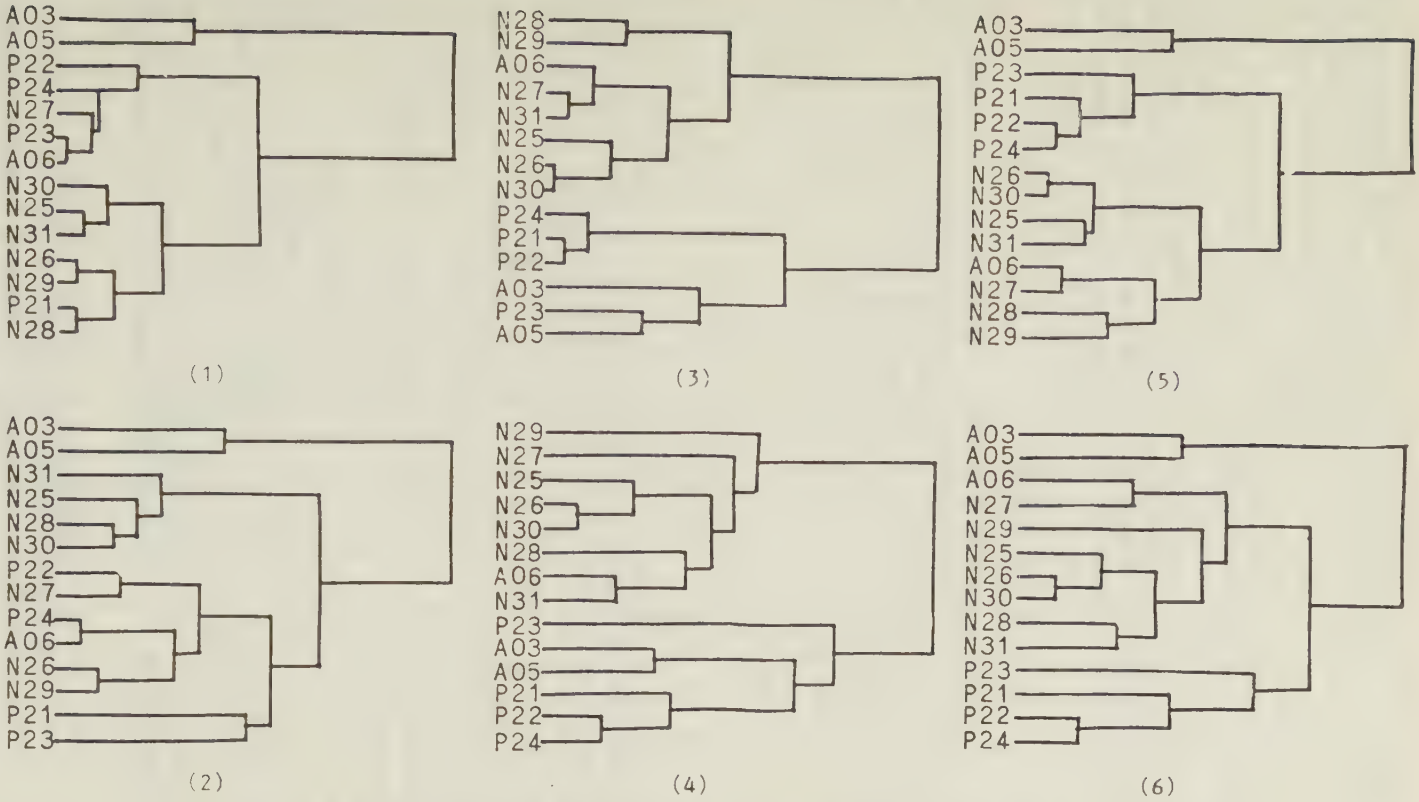

Figure 2. Cluster analyses (dendrograms) of the 14-subject group with inclusion of (1) macrotremor OTP scores, (2) macrotremor OTP, Dif-1 and Dif-2 scores, (3) V7-deviation OTP-scores, (4) V7-deviation OTP, Dif-1 and Dif-2 scores, (5) macrotremor and V7-deviation OTP scores, (6) macrotremor and V7-deviation OTP, Dif-1 and Dif-2 scores. The horizontal axis in each dendrogram represents prediction ratio (0 to 1, left to right).

such as those just mentioned were found between the normals and the psychotic patients, although three of the psychotics (subjects 22-24) scored higher than any of the normals on mean number of macrotremor deviations per period (a), the fourth psychotic (subject 21) being at about the level of the normals. Interestingly enough, that subject reported earlier periodic alcohol abuse. As regards the frequency of occurrence of macro squarewaves a visual analysis of the mingographic recordings suggested only comparatively few to be present, viz about 2-3 per person for the four periods considered.

No clear differences between the subject groups were found on macrotremor Dif-1 scores. Macrotremor Dif-2 scores for each of the measures included indicated the values for the two acute alcohol abusers to decrease over time. The same tended to be true of the normals, but their decreases were less marked. Results for the psychotics were the opposite, all macrotremor measures for this group showing an increase over time. Macrotremor Dif-1 and Dif-2 results for the sober alcohol abuser were similar to those of the normals.

OTP-scores for the V7 measure of total number of deviations (f) were lowest for the two alcohol abusers (the mean number per period being 239 and 207 for subjects 3 and 5, respectively) and for the psychotic patients (the mean number per period for these subjects, 21 and 22, being 165 and 164, respectively). In contrast, the sober alcohol abuser scored highest of all the subjects here (300). Mean size of all deviations (g) in the two acute alcohol abusers and in each of the psychotics was higher than in any of the other subjects. This was reflected in the fact that the number and size of deviations larger than 2.1 degrees was likewise categorically greater for the acute alcohol abusers than in the remaining subjects. Although the number of jerks (j) which occurred was about the same in all groups, the psychotics and the two acute alcohol abusers scored higher than normals on height of the jerks (k), the sober alcohol abuser scoring lowest of all the subjects. On mean slope of the jerks (l), however, a categorical difference was found between all the alcohol abusers and psychotics on the one hand and all normals on the other, the slope being steeper in the former group. The number of recoils (m) did not seem to differ between the groups. The two acute alcohol abusers and subject 23, a psychotic, were highest of all the subjects on percentage of the V7 curve involved in recoils (n) and on number of plateaus (o).

In terms of V7 Dif-1 scores, the number of deviations (f) on V7 was found to increase in the subjects generally under the more attention-demanding conditions. In terms of V7 Dif-2 scores, the same (f) measure was found to decrease generally over time in the alcohol abusers and the normals, and to increase over time in the psychotics.

V7 Dif-1 scores also indicated the number of deviations greater than 2.1 degrees (h) to increase in all three alcohol abusers and to decrease in all three schizophrenic psychotics (21, 23, 24) under the more attention demanding conditions, whereas the normals as a group showed no clear tendency in either direction. In the alcohol abusers V7 Dif-1 scores for number of jerks (j), recoils (m) and plateaus (o) all increased during the more attention demanding conditions. No consistent tendency of this sort was found for the other two groups as regards (j), whereas the normals showed a similar picture and the psychotics an opposite one as regards (m) and (o).

Discussion

Results indicate numerous possibilities for using eye tracking parameters to map out response profiles for the categories of subjects studied here. Although the

groups were small, global measures such as noise/signal ratio, deviation area and microtremor rate appear to at least partly succeed in differentiating the eye tracking performance of normals, alcohol abusers and psychotics. Continued study calls for the on-line analysis of stimulus position, eye position and the subjective representation of the stimulus.

Lipton et al. (1983) have recommended using global measures of smooth pursuit (measures on a level with those of noise/signal ratio and deviation area employed in the present investigation) for studies attempting to characterize patient groups, and using specific parameters such as number of saccades to identify and specify the nature of smooth pursuit dysfunction. One might argue, on the other hand, that for matters much in need of basic research a multidimensional approach which does not exclude the parallel use of both global and more specific measures is best.

Levy et al. (1983) argue that a single finding such as that of abnormal smooth pursuit occurs in many CNS disorders and is thus not specific in itself. They recommend considering quite different measures such as those of oculomotor and vestibular reactivity and the like in conjunction with such a finding. Although by no means arguing against such an approach, one may note that abnormal smooth pursuit need by no means represent a single finding, and that a multidimensional analysis of eye tracking performance, even with a very limited number of recordings, can offer considerable potential for assessing somatic and attentional correlates of pathology of various kinds.

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ON-LINE REGISTRATION OF EYE TRACKING MOVEMENTS IN THE A.C. MODE FOR THE COMPUTATION OF POSITIONAL DEVIATIONS

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This paper summarizes and discusses methodology and recent findings of a series of studies on eye tracking movements in psychotic patients, alcohol abusers and normals, studies employing alternating current (a.c.) amplification for the computation of positional deviations. An on-line system is described involving the use of an electronic pendulum, there being two different tasks, a less attention demanding (following a red light only) and a more attention demanding one (having to press a button each time the light changes to green). Eye tracking using a.c. amplification and a high-pass filter with a long time constant (corresponding to 0.16 Hz) is seen to provide excellent opportunities for the study of multilevel eye-tracking phenomena. A trial with the on-line equipment was designed for exploring, by means of spectography, what frequency components might be connected with the general findings, reported in earlier studies for macro-level tracking to be smoother under more attention demanding conditions and for microtremor rate to increase as cognitive strain increases. The frequency bands of the spectrogram comprising lower frequencies up to about 15-25 Hz were found to decrease in all subjects (n=6; all males, three of them health care personnel and three alcohol abusers) in the more attention demanding as compared to the less attention demanding condition, indicating tracking to be better during the former condition. At the same time higher-frequency bands generally increased during the more attention demanding condition as compared to the less attention demanding condition, the rise here occurring parallel to a corresponding rise in microtremor rate.

The potential difference which normally exists in the eye, such that the cornea is positive with respect to the retina, sets up a steady potential, which shifts with movements of the eye. By means of kinetic electrooculography, the potentials which ocular movements induce at skin electrodes placed around the eyes may be recorded. This requires the use of considerable amplification, since the potentials are only of the order of some tenths of microvolts (Shackel, 1976). Due to the particular periorbital distribution of the electrical field which is present, kinetic electrooculography seems to be the most suitable method for the recording of horizontal movements (Quéré et al., 1981). The recording of horizontal movements is generally performed through the placement of electrodes at the extreme canthi of the eyes, with a ground electrode being attached to the middle of the forehead.

Direct current (d.c.) amplification

The common electrooculographic method for measuring eye-tracking movements employs direct current (d.c.) amplification, a method in which the output signal, theoretically speaking, should correspond exactly with the input signal. In reality, however, such is not the case, the method having the major disadvantage that the presence of electrode drift causes an unstable baseline.

Alternating current (a.c.) amplification

With alternating current (a.c.) amplification, the output signal returns exponentially to the base line, even when the input signal is constant. The decay for this return depends on the value of the time constant selected, very short time constants of only tenths of seconds resulting in almost immediate return.

Within the field of electro-nystagmography, a.c. amplification has been employed for the study of the fast and slow phases of nystagmus through use of short as well as long time constants (Henriksson et al., 1972). It may be argued (op.cit.) that a.c. recording with a short time constant permits the velocity of the eyes but not eye position (degree of deviation) to be studied, whereas a.c. recording with a relatively long time constant (preferably 5 sec.) would avoid problems of d.c. drift and allow nystagmus beats of longer duration to be studied.

Developing the technique

The aim of the methodological work described here has been to develop an on-line recording technique for the investigation of deviant smooth-pursuit through use of electrooculography with a.c. amplification (Andersson, 1983, 1984a, 1984b, 1985). A.c. amplification was selected as the only acceptable alternative, since attempts to use d.c. amplification resulted in intolerably high baseline drift. Initial work in developing a suitable technique involved the constructing of an electronic pendulum for the exact control of stimulus position during tracking (Andersson, 1983).

Earlier versions of such a pendulum involved a 38.5 cm long string of 70 light diodes mounted in a straight line. Through each diode lighting successively for a brief interval, and the sequence of their lighting up reversing when the end of the string of diodes was reached, an illusion of continuous pendular-like movements was produced.

Although the movement displayed could be either of sinusoidal character or of constant speed, the latter type of stimulus was found to be the most discriminating, the majority of the experiments that were carried out using that type of pendulum. In addition, each light-diode could light up either red or green, which occasioned the use of an ABBA-type design for each of the subjects, the first and the fourth of the tracking segments to be analyzed involving red-light-only tasks, the second and the third involving a change of the light to green at short, irregular intervals. Each segment comprised slightly more than 30 secs. Subjects were to press a button each time the light changed to green, a green segment, when it occurred, comprising a one-quarter "swing" of the pendulum in the one direction or the other. In all the experiments, the subjects, who for the most part belonged to psychotic, alcohol abuser or normal groups, were seated 0.5 m from the pendulum, with their head movements being restrained by a chin support.

The first experiments in the series employed a mingographic preamplifier, which drove a Tandberg FM tape recorder. The preamplifier was RC-coupled to balance out d.c. voltage, most of these experiments using a high-pass filter with a time constant of 2.5 sec. Tape-recorded signals were digitized for each of the four slightly over 30-sec segments, such a segment comprising slightly more than 12 pendular cycles. Data-processing involved computing eye position (P) from electrical voltage (V) at each of the sampling points through solving the differential equation $dV/dt = a \cdot dP/dt - b \cdot V$, where dV/dt represents change in V over time. The validity of this measure is based on the assumption that the value of P is always the same for comparable points in any two cycles, and that the P values as a whole (which can be either positive or negative) have a mean value of 0. Each

recording segment was shortened to exactly 12 cycles, a preliminary Fourier analysis being used in identifying cycles. A correction was employed for the existence of whatever small drift might (despite of a.c. amplification) be present, a correction which consisted of subtracting from V its mean value within each cycle. A more thoroughgoing Fourier analysis followed.

Measures employed in the first studies

In the first four studies (Andersson 1983, 1984a, 1984b, 1985), the following measures were obtained for each of the four periods:
(1) Noise/signal ratio: the ratio between the sum of the squared amplitudes of the 2nd to 6th harmonics, and the squared amplitude of the major wave (1st harmonic).
(2) 2nd to 6th harmonics, the ratio of the respective higher harmonic factor to the 1st harmonic factor. These values were related to the ideal values calculated for what would be perfect tracking.
(3) Deviation area: the area between the two curves describing the movements of the pendulum and of the subject´s eyes, respectively, a low value indicating the subject to be following the pendulum closely.
(4) Microtremor rate: (d(tot)-d(eff))/d(eff), where d(tot) represents the total distance and d(eff) the "effective" distance the eye covered, and where d(tot) and d(eff) represent the sum of all small eye movements, as measured by recording eye position at 3.66 msec intervals, and at intervals nine times larger (33 msec), respectively.
Overall tracking performance (OTP); Dif-1; and Dif-2: For each measure above, a summary measure of the subject´s overall tracking performance was calculated, as were two difference scores. Dif-1 indicates the effect of changing from the less attention demanding (red-light only) to the more attention demanding conditions (changing light color). Dif-2 represents the effect of practice.

Results of macrolevel and microtremor analysis

In the first study (Andersson, 1983) schizophrenics (n=13), cycloid psychotics (n=9) and normals (n=4) could be readily distinguished in terms of eye tracking performance. A cluster analysis together with criterion values for indicies based on various of the measures mentioned above yielded correct classifications in all but four cases. Patients´ performance was found, for most measures, to be considerably better on the more attention-demanding than on the less attention-demanding task.

In the second study (Andersson 1984a) nineteen psychotic patients, most of these tested twice, provided cross-validational support for many of the previous findings. Both deviation area and noise/signal-ratio differentiated rather clearly between cycloid psychotics and schizophrenics. Cycloid psychotics, who could be expected on the basis of Leonhard´s work (1957, 1979) to show phasic changes, seemed to show these on both noise/signal ratio and deviation area, the change on the latter measure suggesting improvement, the cycloid psychotics shifting between the first and the second testing (within a week) from being worse in performance than schizophrenics to not differing from them. Generally speaking, patients showed better performance under the more than under the less attention demanding conditions, as obvious from comparisons with the ideal tracking curve. The lone exception, here as in the earlier study, was in regard to the 5th harmonic. Inferior performance under the more attention demanding conditions there seemed to be reflective of the cognitive strain the complex conditions involved. Interestingly enough, microtremor rate was found to increase with an increase in cognitive strain, but to nevertheless decrease over time.

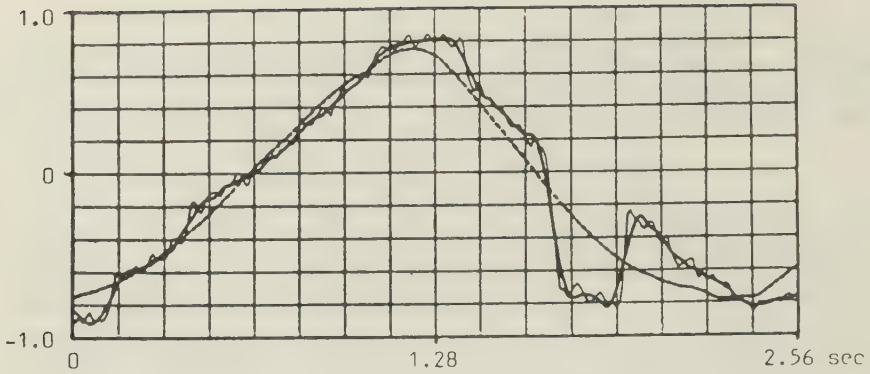

Figure 1. Eye-tracking segment (2.56 sec) from the record of a male alcohol abuser (age 34), illustrating the computation of eye position (lighter line), the V4-curve (darker line) and the V7-curve (dotted line). The presence of a macro-square wave in the latter part of the recording is evident.

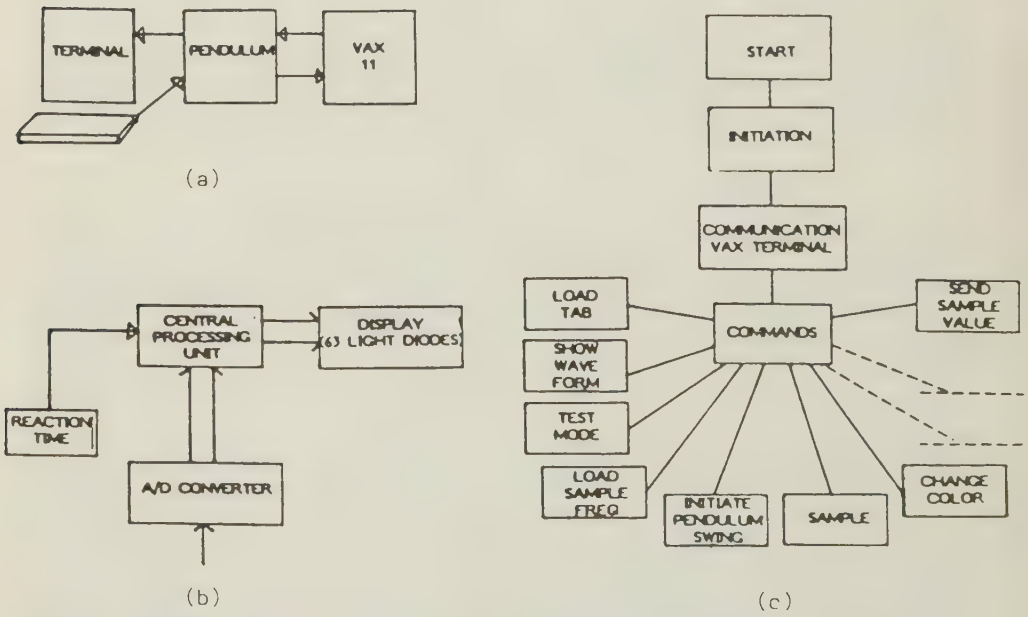

Figure 2. Schematic representation of the on-line eye-tracking system. The system works in transparent mode (a). Upon the occurrence of certain predetermined escape sequences the electronic pendulum reacts to certain commands (b). The program structure is illustrated in (c).

In the third and fourth studies (Andersson 1984b, 1985), 20 alcohol abusers were compared with the 19 psychiatric patients and the 4 normals already reported on. The results of repeated retests of 15 of the alcohol abusers during a three-month period were also examined. Although psychotic patients could not be distinguished from alcohol abusers on overall measures of noise/signal ratio and deviation area, microtremor rate was found to be categorically higher in psychotic patients than in alcohol abusers. This, together with certain other results suggested possible disturbances of a central nature in the psychotic patients.

In the original mingographic recordings a striking characteristic was found for the majority of alcohol abusers. This was the frequent occurrence of macro square-wave jerks in the same direction as that of the moving target, involving an initial saccadic deviation of at least 10 degrees amplitude from current tracking, followed (after a normal reaction time of about 200 msec) by a catch-up saccade in the direction opposite to the initial saccade. Such deviations were found to a significantly more frequent extent in alcohol abusers than in psychiatric patients.

A more extensive analysis of macrotremor

These findings suggested that a more extensive analysis of different types of deviations evident in the mingograph recordings might be promising (Andersson, 1985). Each individual record, comprising 12 periods of 12 waves each, was smoothed by computing sliding means over 16-point intervals, each such interval corresponding to 10 msec. Such a smoothed curve will be referred to as the V4 curve (Figure 1).

The V4 curve closely resembles the original curve, except for a certain obviously unconscious tremor, referred to here as macrotremor. Macrotremor was computed by counting upward or downward deviations of eye position from the V4 curve and then identifying bands of adjacent deviations. Analysis of jerks involved examining deviations of the V4 curve from the V7 curve, where the latter curve form was obtained by computing sliding and weighted means over 128-point intervals, the weighting utilizing the midpoint of a second degree regression (see Figure 1 for an illustration). As could theoretically be expected, this curve tends to coincide closely with the original stimulus movement. Deviations from this curve were identified. Changes sufficiently long and steep were classified as jerks. A jerk was at least double the speed of the stimulus, with the criterion for size being arbitrarily set at 0.15 of the maximum amplitude, i.e. 3.15 degrees.

A deviation that began and ended with a jerk was classified as a macro square-wave jerk if the line between the jerks was flat, horizontal, and of a certain minimum temporal size.

Cluster analyses based on macrotremor and V7-deviation, and on OTP, Dif-1 and Dif-2 scores (see above), applied to the recordings of a group of 14 subjects (seven normals, four psychotic out-care patients and three alcohol addicts, two of which were acutely intoxicated), succeeded quite well in distinguishing at the three-cluster level between the two acute alcohol abusers, the four psychotics and the seven normals, the sober alcohol abuser being found in the same cluster as the normals (Andersson, op.cit.). The results were seen as suggesting that the best approach to the analysis of eye movements is a multidimensional one which does not exclude the parallel use of both global and more specific measures.

Table 1A. Distribution of frequency components, 0-50 Hz.
Sums of amplitude values in the respective frequency intervals (0-5, 5-10, ... , 40-50 Hz). Microtremor rates (for computation, see text) are included for comparison. An increase in values under the more attention demanding conditions is indicated by underlining. N = normal subject, E = alcohol (ethanol) abuser.

ject	Hz										Micro-tremor
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	rate
A	7.16	0.72	0.16	0.36	0.31	0.29	0.20	0.19	0.17	0.16	1.57
B	6.71	0.67	0.56	0.36	0.43	0.35	0.26	0.28	0.33	0.28	3.76
A	7.50	1.04	0.64	0.50	0.55	0.56	0.38	0.41	0.41	0.50	4.26
B	8.08	0.87	0.52	0.44	0.45	0.71	0.63	0.47	0.44	0.55	4.93
A	5.05	0.66	0.51	0.35	0.36	0.33	0.31	0.24	0.25	0.22	3.12
B	3.92	0.53	0.39	0.33	0.36	0.33	0.39	0.29	0.29	0.26	3.88
A	9.45	1.62	0.95	0.57	0.45	0.38	0.28	0.22	0.18	0.18	1.68
B	8.61	1.12	0.75	0.53	0.45	0.43	0.35	0.30	0.26	0.26	2.58
A	14.81	2.91	1.21	0.60	0.40	0.38	0.34	0.35	0.35	0.33	2.76
B	8.07	1.58	0.94	0.63	0.45	0.45	0.40	0.37	0.33	0.34	3.42
A	9.38	1.04	0.58	0.43	0.40	0.32	0.34	0.29	0.30	0.27	4.08
B	6.57	0.64	0.43	0.38	0.35	0.31	0.32	0.28	0.25	0.29	3.97

'alues of frequency components under (A) normalized.
First value (0-5 Hz) = 1000.

ect	Hz									
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
A	1000	100	84	50	43	40	27	26	24	22
B	1000	110	83	64	54	52	43	40	44	43
A	1000	138	84	66	73	75	50	54	55	66
B	1000	122	73	61	62	100	88	65	62	78
A	1000	130	101	68	70	64	60	47	49	42
B	1000	135	99	85	92	85	101	74	73	65
A	1000	171	100	60	47	39	29	22	18	19
B	1000	129	87	61	53	50	40	35	29	29
A	1000	196	81	40	27	25	23	23	23	22
B	1000	195	116	77	55	55	50	45	40	42
A	1000	110	62	45	43	33	35	30	31	28
B	1000	97	64	57	52	47	48	43	39	43

A trial with the on-line equipment

Following the experiments which were just described, an on-line system was constructed, one fully controlled by the central processing unit of a VAX 11 minicomputer (Figure 2). The system works in transparent mode; however, during certain predetermined escape sequences the pendulum reacts upon the occurrence of certain commands. Thus, for example, special commands may be used for loading the routines to be shown on the display, for determining the frequency of A/D sampling, for changing the stimulus color (to red or green), for measuring the reaction time to such changes, and for sending sample values from the pendulum to a buffer in the central unit which stores the values.

A high-pass filter with a relatively short time constant had been used in some of the earlier experiments, requiring major transformations of the original curve for the computation of eye position. Experience with using a high-pass filter with a longer time constant (corresponding to 0.16 Hz) had indicated that employing differential transformation for the computation of eye position resulted in only small or neglible changes. It was thus obvious that, since the lower frequency limit was 0.16 Hz, there was no need for using correction procedures, inasmuch as the stimulus cycle used was higher (0.33 Hz).

Method. An initial experiment employing this on-line equipment was performed, using a high-pass filter with the longer time constant (corresponding to 0.16 Hz). The experiment, comprising a small number of subjects, was designed to explore, by means of spectrography, what frequency components might be connected with the findings reported above concerning macro-level tracking being better under the more attention demanding conditions and of microtremor rate tending to increase as cognitive strain increases. Digital Fourier transforms of the input signal (using Hanning-window) were employed for analyzing the frequency components of records from a 30-sec red-light-only (less attention demanding) and a 30-sec red-and-green (more attention demanding) task. Microtremor rate was calculated using the measures described above.

Subjects. Six subjects were included in this study. All were males, three of them being health care personnel (subjects N1-N3, ages 41, 21 and 37, respectively) and three being alcohol abusers (subjects E1-E3, ages 39, 59 and 47, respectively), available at the primary care center during the period of testing. Of the alcohol abusers, subject E1 had stopped drinking the day before testing, after a period of heavy alcohol consumption, whereas subjects E2 and E3 reported they had been sober for the last three and nine months, respectively.

Results and Interpretation. The spectrographic analyses yielded results quite in agreement with those obtained earlier using the more complicated method for the computation of positional errors. The output at the lower frequency bands (up to 15 Hz) was found to decrease for all subjects under the more attention demanding as compared with the less attention demanding condition (Table 1A). This result corresponds with the earlier findings of tracking performance tending to improve generally under a more attention demanding condition. The normals tended to show values for the lower frequencies which were lower than those of the alcohol abusers, suggesting here as in the previous studies that tracking tends to be impaired in the latter group.

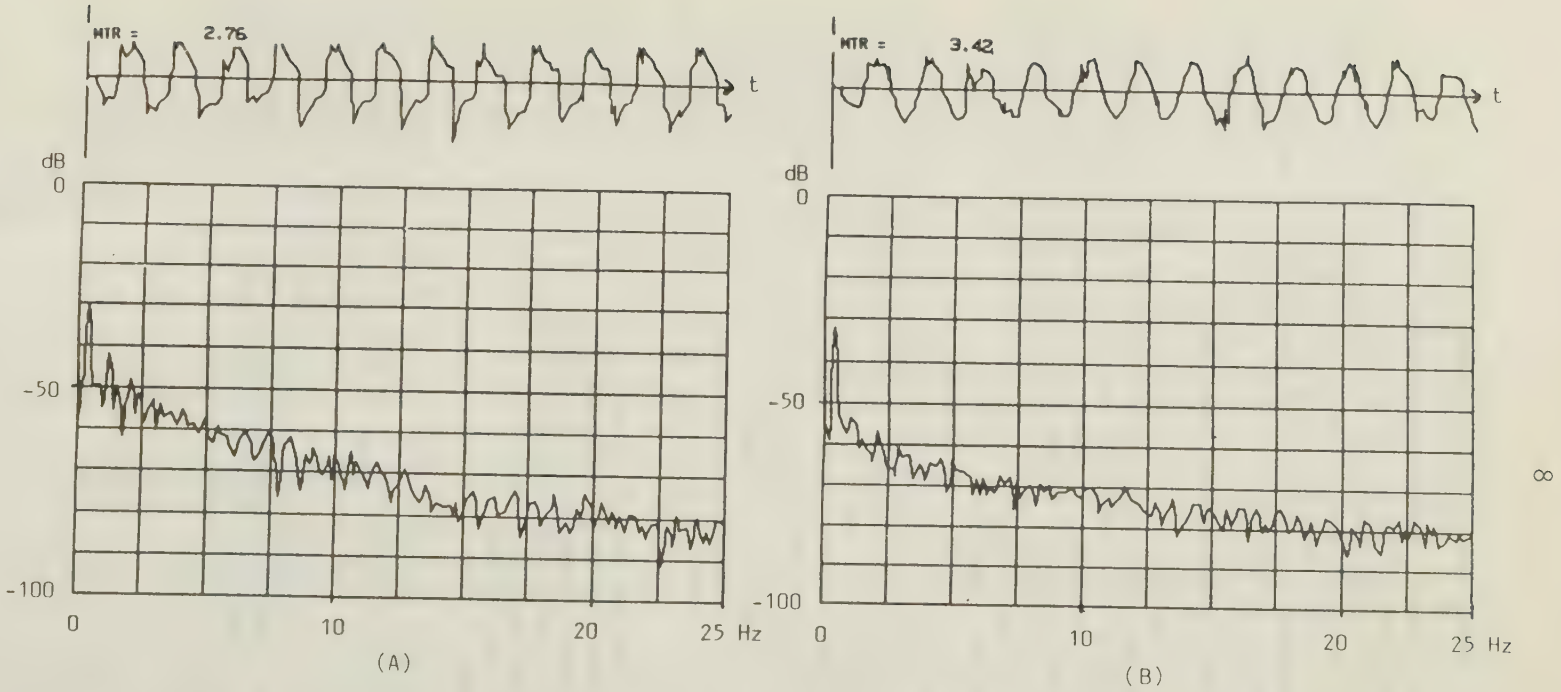

Figure 3. Upper half: 30-sec eye-tracking curves under less (A) and more (B) attention demanding conditions in an alcohol abuser (subject E2). Lower half: spectral analyses of the curves: x-axis 0 - 25 Hz; y-axis a logarithmic scale with 10 dB per division. Note the greater energy in the lower frequency bands (transition point at about 15 Hz) in (A) compared with (B). MTR = microtremor rate.

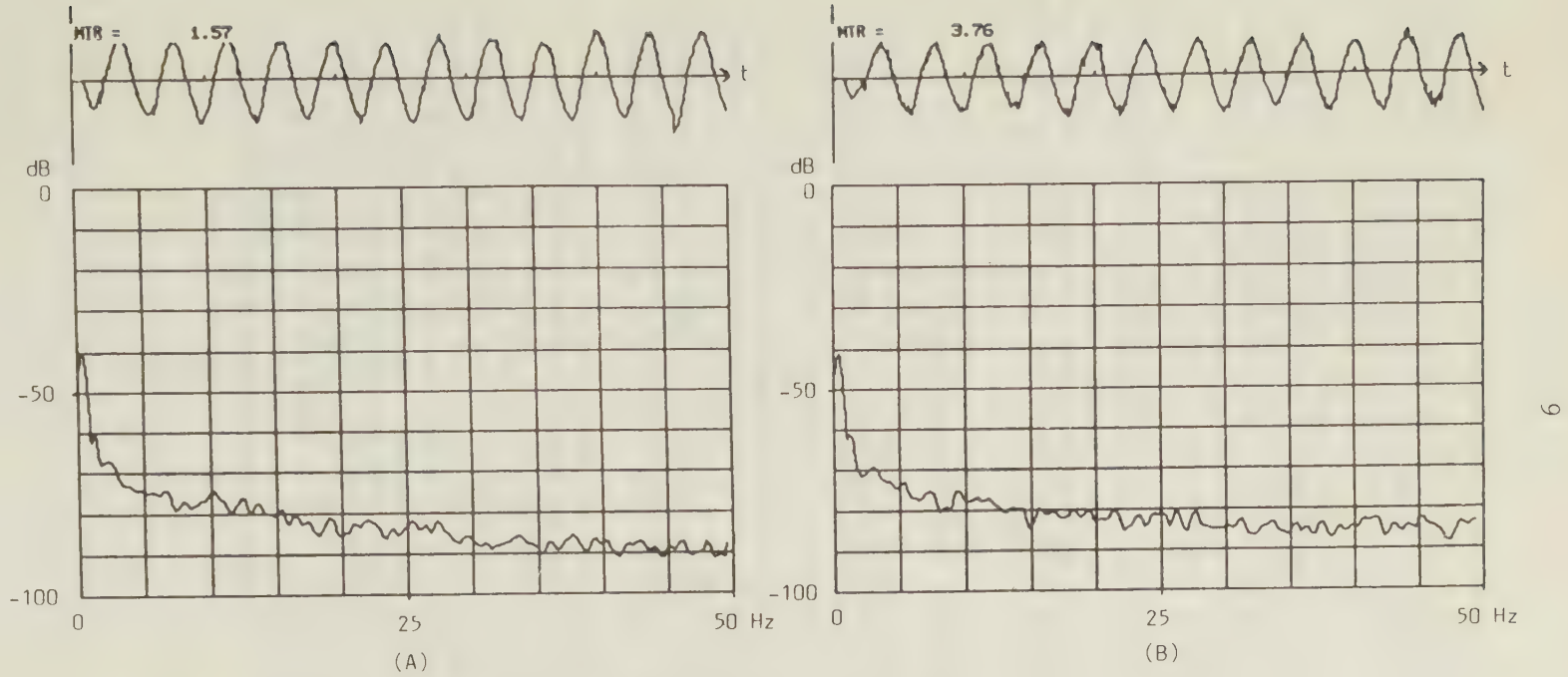

Figure 4. Upper half: 30-sec eye-tracking curves under less (A) and more (B) attention demanding conditions in a normal subject (subject N1). Lower half: spectral analysis of the curves: x-axis 0 - 50 Hz; y-axis a logarithmic scale with 10 dB per division. Note the greater energy in the higher frequency bands (transition point at about 20 Hz) in (B) compared with (A), and that differences between (A) and (B) are only slight in the lower frequency bands.

At the same time, microtremor rate increased generally in all three normal subjects under the more as compared with the less attention demanding condition. The rise of microtremor rate here occurred simultaneously with an increase in signals of higher frequency bands, i.e., from approximately 25 Hz to 50 Hz or higher, transition frequencies ranging from 15-30 Hz (Table 1A).

A similar increase both of higher frequency bands and of microtremor rate under the more attention demanding condition was also found in two of the three alcohol abusers (subjects E1 and E2). The third alcohol abuser (E3), however, was relatively high in microtremor rate under both the less and the more attention demanding conditions and tended to show a decrease in the frequency bands up to 45 Hz under the latter conditions.

As is evident in Table 1B, however, normalizing values for the frequency components through assigning the frequency band of 0-5 Hz a value of 1000 and expressing the values of the other frequency bands in terms proportional to this, nevertheless indicated a tendency for the relative energy within the higher frequency bands, those of 25-50 Hz, to increase under the more attention demanding conditions for all the six subjects.

Illustrations of the results of the spectral analyses of the recordings of two of the subjects (E2 and N1) are found in Figures 3 and 4.

Discussion. In sum, therefore, "on-line" eye tracking using a.c. amplification and a high-pass filter with a long time constant (corresponding to 0.16 Hz) is seen to provide excellent opportunities for studying multilevel eye-tracking phenomena. Spectrographic analyses and the normalization procedures which have been discussed may be useful for studying the frequency components involved in tracking. The normalization procedures which have been discussed would appear to offer considerable potential for the microtremor phenomenon. Information obtained through spectrographic analyses, however, does not seem to succeed in distinguishing between various types of macro-level deviations. Thus, various other types of measures are needed for such purposes (see Andersson, 1985, for a description of certain measures of this sort which could be included in an on-line analysis).

The existence of both higher and lower level trajectory controls, which may influence each other mutually, might serve to explain some of the findings concerning macro- and micro-level tracking reported in a series of studies by the present author (Andersson, 1983, 1984a, 1984b, 1985). It can be hypothesized that microtremor tends to function together with microsaccades and ocular drift in lower level trajectory control. If this lower level of control cannot be optimized because of limitations in information processing capacity, higher levels of control may be involved, the solutions thus attempted resulting in suboptimal trajectories. The study of adaptive resources at both lower and higher levels may shed light upon the much discussed question of whether the saccadic and smooth tracking systems are independent, and may suggest that an interaction of velocity and positional information takes place, not only at higher and lower levels but also between such levels. One inter-level link may be saccadic suppression (cf. Zuber and Stark, 1966), which it can be suggested may influence activity at higher and lower levels differently.

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Errata

Paper II. Whenever it appears, the term "signal/noise ratio" should be replaced by "noise/signal ratio";

p. 465 line 10: "Nyman (1978)" should read "Nyman (1975)".

Paper III. p. 491 line 11: "(nos. 4," should read "(nos. 4, 8,";

p. 492 line 5: the formula should read "$dV/dt=a \cdot dP/dt - b \cdot V$";

p. 492 line 5 from the botton: "24" should read "24h";

p. 494 line 12: "0.737" should read "2.737".